NUCLEONICS

TECHNIQUES AND APPLICATIONS OF NUCLEAR SCIENCE AND ENGINEERING

May, 1951

Shielding wall erected to test special concrete blocks

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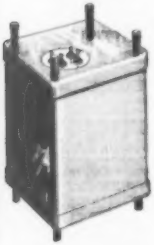

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NUCLEONICS

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Vol. 8, No. 5

THE COVER shows a concrete shield block being lifted into place at Argonne National Laboratory in a wall built to determine how well the blocks fit together. Made by the Austin Co., the 150 lb/ft³ blocks will eventually be used to build nuclear research cells. Steel cores in keyways give vertical alignment; lead strips cover horizontal joints. *Also see p. 78.*

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Future Utilization of Isotopes

Since the first shipment of radioisotopes from Oak Ridge in 1946, annual shipments have increased by 300%. But the surface has only been scratched on possible uses. This is certainly the case in industry. Of 14,589 isotope shipments made by AEC in 4½ years, only 4% have gone for industrial research.

In Cleveland last month, AEC Commissioner Glennan looked into the future of industrial utilization of radioisotopes. He said, "It is the ultimate objective of the AEC to work itself out of the isotope business." AEC looks towards the day when industry instead of the government will produce and sell isotopes.

A considerable increase in demand for isotopes will be necessary before industry might find the work economically feasible. For a growth of the isotope "industry," four things are needed, according to Dr. Glennan: *1.* Vastly greater numbers of people must be trained in the techniques of handling isotopes. *2.* Industry must consider the health and safety factors involved in the large-scale use of radioisotopes. Here Dr. Glennan pointed out that use of isotopes will have to be supervised in the same way as are other toxic and hazardous materials—by state and local public health officials. *3.* Industry must carefully consider the economic factors involved. *4.* Industry must intensively study all possible uses of isotopes—in process control, production, testing and research. Dr. Glennan stated that industry must take the lead in such studies, in contrast with the fission-product study by the Stanford

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Research Institute, sponsored by AEC (see page 5 for details of this study).

The day before Commissioner Glennan spoke, AEC announced a proposal by the Bendix Aviation Corporation to undertake a privately financed feasibility study of a nuclear reactor to produce radioisotopes on a commercial basis. In his talk, Dr. Glennan raised questions which such a study would have to answer: What new production techniques might make production economic? How big is the ultimate market for isotopes? How will the price affect this market?

The results of this study will be very interesting and may serve as a key to the growth of the nucleonics field. We are optimistic about what the results will show.

Declassification Committee

Appointment of an engineer to AEC's Committee of Senior Responsible Reviewers was recommended several months ago by AEC's Hoc Committee on Technological Information for Industry. These reviewers are the principal advisors to the AEC on declassification matters. A vast amount of engineering information is produced in the atomic energy program. Thus, it would appear that naming of an engineer to the present committee of three physicists and two chemists would expedite declassification of such information. Although it may be difficult to locate a man with the broad background necessary, we hope for an early appointment to this position. —J. D. L.

Random Notes

• *As a subscriber to* NUCLEONICS, *you may have been one of the several hundred people approached last month by a member of the staff of the McGraw-Hill Research Department and questioned on the extent of your readership of the March issue of* NUCLEONICS. *This fall a second readership survey will be conducted, this time by mail, on another of our issues.*

These surveys provide the editors with first-hand information on what our readers' interests are. As with every scientific journal, the editors of NUCLEONICS *must determine its scope and coverage according to the desires of its readers. And the very best way to find out about these desires is to go directly to you, the reader.*

We did this in connection with the third and fourth issues which we published (November and December, 1947). The results of that survey showed, for one thing, that the ten pages of abstracts which we published monthly got a very low readership. However, we weren't convinced that it wasn't worth publishing these abstracts—and so we continued them. But a year and a half later, we conducted a special mail survey on abstracts alone. On the basis of this survey, we decided that it would be worthwhile (from the

(Continued on page 94)

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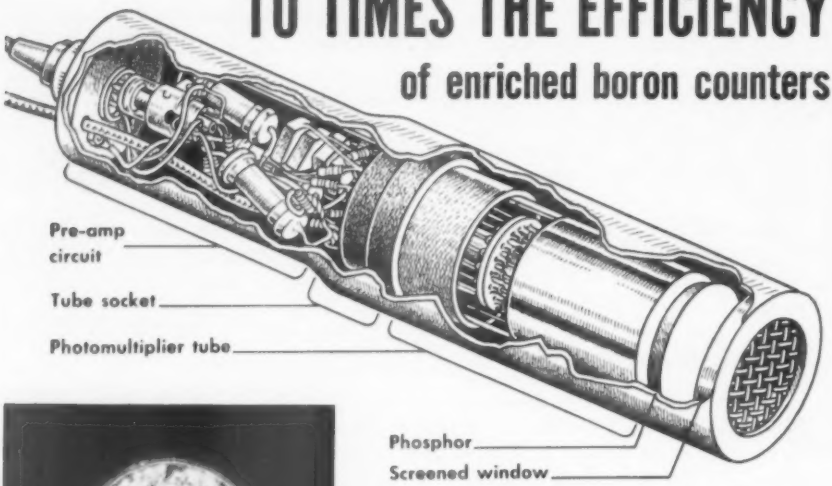

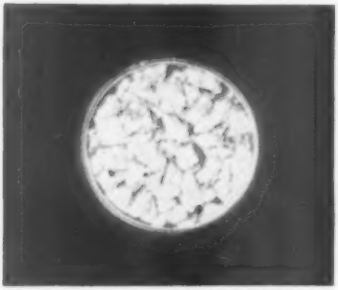

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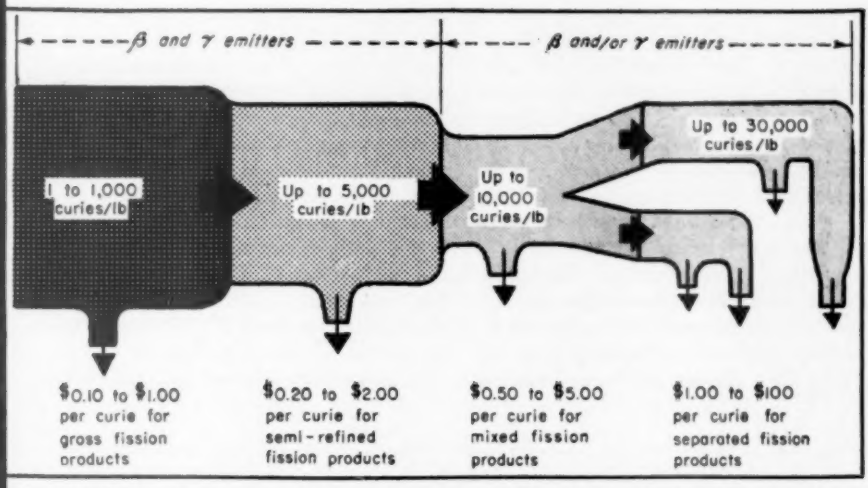

β and γ emitters
β and/or γ emitters
1 to 1,000 curies/lb
Up to 5,000 curies/lb
Up to 10,000 curies/lb
Up to 30,000 curies/lb
$0.10 to $1.00 per curie for gross fission products
$0.20 to $2.00 per curie for semi-refined fission products
$0.50 to $5.00 per curie for mixed fission products
$1.00 to $100 per curie for separated fission products

If industry shows enough interest in the use of fission products, charges will run roughly as shown above

Industrial Utilization of Fission Products

In its operation of nuclear reactors, the U. S. Atomic Energy Commission produces vast quantities of fission products as by-products of plutonium production. Now, most of these fission products are stored underground in large concrete vaults. To eliminate this and to offer industry the possibility of working with fission products, the AEC asked the Stanford Research Institute to study potential industrial applications. Presented here are highlights from the preliminary report prepared by the Stanford group

DURING THE PRODUCTION of plutonium in the reactors at Hanford, uranium-235 is fissioned, producing isotopes which are, in general, radioactive and are in an atomic weight range of 72 to 162.

A list of the fission products possibly useful in large quantities is shown in Table 1. Significance for inclusion in this table is based on a yield of more than 0.5%, a half-life of longer than 40 days or an energy level of over 0.1 Mev.

Radioactivity is the property of fission products that is potentially of greatest usefulness to industry. Use of the material for its chemical or other physical properties does not appear promising (except for very specialized cases) because of the very high cost per pound. However, the cost per curie would be very low compared with radioactive materials sold at present. Thus, the important properties to consider are those associated with radioactivity.

It is possible to obtain these or similar radiations from sources such as other radioisotopes, electron generators, and

X-ray machines. The best source of the desired radiation must be determined by the development of the technical and economic factors involved in each specific use. The main advantage of using fission products appears to be the possibility of obtaining large amounts of radioactivity at a low cost.

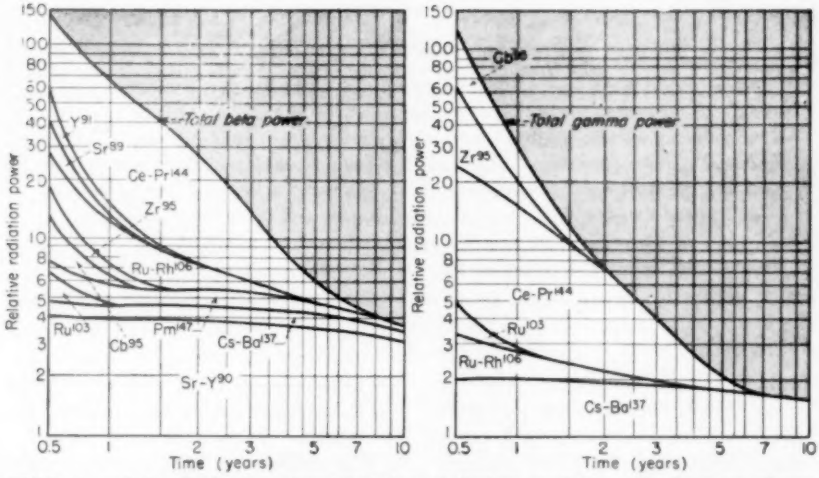
The energy at which the beta particles and gamma rays are emitted is of importance. Beta particles emitted by fission products have energies as high as 3.5 Mev. Gamma rays given off by fission products have energies up to 3.8 Mev. The fission products emitting gamma rays of high energy in general have short half-lives. Thus, after a six months decay period, very few high-energy gamma radiations are emitted.

In evaluating material as a radiation source it is important to consider the amount of radioactivity in curies per unit weight of total material. The intensity of radiation received from a source depends not only on the magnitude of the source in curies but also on the total weight and volume of space in which the activity is contained. In many uses a very concentrated source of radioactivity would be required.

TABLE I
Characteristics of Significant Fission Products

Isotope	*Symbol*	*Yield (%)*	*Half-life*	*Beta energy (Mev)*	*Gamma energy (Mev)*
Strontium-89	Sr	4.6	55 days	1.50	None
Strontium-90	Sr	5.3	25 years	0.61	None
Yttrium-90*	Y		62 hours	2.3	None
Yttrium-91	Y	5.4	57 days	1.53	None
Zirconium-95	Zr	6.4	65 days	0.39 (98%) 1.0 (2%)	0.73 (93%) 0.23 (93%) 0.92 (7%)
Columbium-95*	Cb		35 days	0.15	0.76
Technetium-99	Tc	6.2	1×10^6 years	0.3	None
Ruthenium-103	Ru	3.7	41 days	0.25 (95%) 0.8 (5%)	0.5
Ruthenium-106	Ru	0.5	1 year	0.03	None
Rhodium-106*	Rh		30 sec	3.5 (82%) 2.3 (18%)	0.51 (17%) 0.73 (17%) 1.2 (1%)
Cesium-137	Cs	6.2	33 years	0.5 (95%) 1.19 (5%)	None
Barium-137†	Ba		2.6 min	None	0.66
Cerium-144	Ce	5.3	290 days	0.35	None
Praseodymium-144*	Pr		17.5 min	3.0	0.2 1.2
Promethium-147	Pm	2.6	4.4 years	0.22	None

* Radioactive daughter of preceding element with same atomic weight.
† Metastable state: Excited state that changes to ground state without beta emission.



FIGS. 1 and 2. Radiation characteristics of fission products. Each curve shown represents total radiation power for all isotopes appearing below that curve. Relative radiation power, the product of emitted particles and the energy of each particle, is used since it is a direct indication of the ability of the fission products to do work

Sources of radioactivity in low concentrations will absorb considerable amounts of their own radiation. This is particularly true in the case of beta emitters, where a thickness of over a few millimeters will cause a self-absorption of all the radiation emitted from the interior of the source.

TYPES OF FISSION PRODUCTS

It is possible that the fission products could be used in crude, refined or separated forms. Described below are some of the ways in which fission products could be made available in large quantities.

Gross Fission Products

Uranium and plutonium are separated chemically from the rest of the mass present after irradiation in a chain reactor. This leaves a "soup" which includes fission products, water, salts, and other contaminants. This crude heterogeneous mass, with only water removed, is defined here as *gross* fission products. Since the technology of reactor operation and chemical separation is constantly changing, specific information cannot be given on the form in which gross fission products could be made available. The isotopes of Table 1 would be included in any of the gross fission product masses but it is expected that the material that could be made available in the next few years would have an activity of only a few curies per pound. Other foreseeable sources of gross fission products, however, could result in activities up to thousands of curies per pound.

Figures 1 and 2 present graphically some radioactive properties of a heterogeneous mixture of fission products. These figures show the decay of the total activity versus time and also indicate the amount contributed to the total radiation by the significant isotopes.

Semi-Refined Fission Products

Gross fission products that have been processed to remove some of the nonradioactive contaminants are defined

Prospectus for Management

As indicated in this article, the primary purpose of the Stanford Research Institute study is to determine the extent of industrial interest in the use of fission products. Data collected will be used to estimate very roughly potential markets for fission products. These estimates will be used to guide a research and development program into the most worthwhile channels (i.e., uses with the largest potential markets) as well as assisting the AEC in planning processing and distribution programs.

Copies of the preliminary report may be obtained from Project 361, Dept. of Business and Industrial Economics, Stanford Research Institute, Stanford, Calif.

here as *semi-refined* fission products. The only difference between this group and gross fission products is a higher concentration of radioactive materials and therefore a higher activity in curies per pound of total material.

Mixed Fission Products

Further processing could be made upon the fission product mass by separation into groups of radioisotopes—*mixed* fission products. The primary reason for making such a separation would be to obtain groups that emit a more specific radiation. It would be particularly important to do this if only beta rays were to be used. By eliminating gamma rays the health hazard and the shielding and handling precautions could be appreciably reduced, making it worthwhile to pay for extra processing. Limited quantities of some mixed fission products are presently available from the Isotopes Division of the AEC to qualified users.

Separated Fission Products

Further separations can be made into specific isotopes—*separated* fission products. Some of these, if processed in large quantities, could be made available cheaply as long as extreme chemical purity was not required. These separated fission products appear desirable in cases where a specific radiation is required. The most important separated fission products, such as Sr^{90} and Cs^{137}, are available at present from the Isotopes Division.

The radioactive properties of gross fission products, semi-refined fission products, and mixed fission products are determined by the aggregate of the isotopes that make up each such category. Simple additive calculations can thus be made to indicate the characteristics of any possible group that can be produced. As is indicated in Figs. 1 and 2, it is anticipated that fission products could be made available at an age of 6 months.

POSSIBLE INDUSTRIAL USES

Many of the suggestions for the possible use of fission products stem from the proven applications of the past. The lower price and larger available quantities of fission products may, in some cases, make them attractive for these established uses. In other cases, the suggestions for possible use given are speculative in character and are not based upon actual industrial experience.

Use of Biological Effects

The effect of radiation on living organisms can be classified as one of the major properties of fission products that could be used for constructive industrial uses.

Killing organisms. Studies have been made by the Massachusetts Institute of Technology* to determine the amount of radiation necessary to kill organisms commonly contaminating everyday products. In general, from 500,000 to 2,000,000 r are necessary to kill all the bacteria present in a culture, whereas less than 100,000 r are required for common pasteurizations. The amounts of radioactive material required to produce the quantity of radiation for sterilization would probably be on the order of 100 curies per pound of material processed per day. Since the bacteria are killed by the ionizing properties of radiation acting on the organisms themselves, there is not any appreciable temperature rise in the material being sterilized. This fact opens the way to many improvements in food processing as practiced today. For example, it may be possible to sterilize some foods in packages while still retaining the original fresh food taste.

Destruction of ability to reproduce. Radiation also has the property of destroying an organism's ability to reproduce. When dealing with micro-organisms, it is difficult to determine whether an organism has been killed or merely had its ability to reproduce destroyed, since its reproduction and life cycles are so short. Larger organisms, such as weevils, might be effectively controlled by using the much lower quantities of radiation necessary to destroy their reproductive ability.

Artificial aging of foods, etc. Brief examination suggests other areas in the general category of biological effects which may be worth further investigation and thought. Typical of these possibilities are suggestions for the artificial aging of meat, whisky, and other products. These suggestions are of a speculative nature and are not based upon actual experience.

Initiation of Chemical Change

The chemical changes caused by radiation result in the breakdown of molecules into parts (free radicals) which may then recombine to form a different product.

Chemical reactions requiring a large number of free radicals in relation to the total amount of molecules formed require large quantities of radiation. Such reactions would only appear practical for high priced specialty chemicals. A more promising type of reaction is one which requires a small number of free radicals in relation to the total amount of product that would be obtained. This type of reaction may be termed a "chemical chain reaction," and the effect of radiation in this case would be to provide "triggering" energy. Similar industrial processes exist today in which light, another form of radiation, acts as the triggering mechanism.

Considerable study has been devoted to the effect of radiation on chemicals to determine what free radicals are formed. Little effort, however, has been directed towards finding chemical reactions which may have industrial value. Up to the present, studies for industrial chemical reactions have been limited because low cost sources of radioactivity have not been available.

Chemical breakdown. Many chemicals undergo a chemical breakdown when exposed to radiation. This results from the free radicals formed combining into smaller molecules than the original. Water, for example, in the presence of radioactivity will break down to hydrogen, oxygen, and hydrogen peroxide.

Polymerization. Molecules, when joined together in a long chain, can

* C. G. Dunn, W. L. Campbell, H. Fram, A. Hutchins. Biological effects of high energy, electrostatically produced roentgen rays and cathode rays, *J. Applied Phys.* **19**, 605. Also J. G. Trump, R. J. Van de Graaff. Irradiation of biological materials by high energy roentgen rays and cathode rays, *ibid* **19**, 599 (1948).

produce a new chemical by a process called polymerization. For example, many molecules of the common gas ethylene join together to form the plastic polyethylene. This type reaction is common today in many industrial chemical processes and may be stimulated by radioactivity.

Halogenation. When the halogens (chlorine, bromine, iodine, fluorine) are joined to other chemicals to produce a compound, the process is called halogenation. Ethylene dichloride, a raw material for producing tetraethyl lead, is produced by the reaction of ethylene and chlorine, which is a halogenation or chlorination reaction. It is possible that difficult halogenations can be accomplished by having radioactive materials or radiation present to supply an energy of activation.

Oxidation. Oxidation reactions may be stimulated by producing free radicals in the presence of oxygen. This possibility is important since it could have an effect on the industrially important field of hydrocarbon oxidation.

Ionization of Gases and Liquids

Practical uses of the ability of radiation to ionize gases and liquids include the following:

Static eliminators. Static eliminators employing radioactive material emitting alpha particles are commercially available. There is reason to believe that beta-emitting fission products might find comparable use in this type of equipment.

The entire field of grinding materials into small particles is faced with the problem of particle flocculation and limitation of particle size due to agglomeration caused by static electricity.

Gas discharge tubes. Certain electronic tubes, such as the common fluorescent light tube, require a build-up of voltage before they begin to function by ionizing the gas contained in them. If radioactive materials were introduced into these tubes, a permanent state of ionization would be produced which should lead to quicker, more efficient starting of the tube at lower voltage requirements. The amount of radioactivity required per tube would be exceedingly small.

The industrial technology for this application has already been developed using a pure isotope. It appears that beta-emitting fission products may also be found useful for this purpose.

Miscellaneous. Many other potential uses for fission products are dependent on the ability of radiations to ionize liquids or gases, or in some way to break down the original molecule into intermediate products which will assist in a reaction or operation.

In many electrochemical reactions, such as in electrolysis and electroplating, it may be possible to improve the over-all efficiency of the process by using radiations from fission products to ionize the reaction medium into intermediate products. The effect on the reaction would be to reduce the total power requirement by lowering the overvoltage.

Another possible use for fission products might be to assist in combustion processes where it is important to obtain a rapid rate of flame propagation. In this case a gas would be the medium for the chemical or ionic breakdown rather than a liquid. The speed-up in the combustion chain reaction would result from the ionization of the air or gas to form intermediate chemical products which assist burning.

Radiography, Controls and Tracing

The ability of the radioactive fission products to be detected through the use of instruments such as Geiger counters and suitable film enables the development of many interesting and useful techniques for measuring and controlling industrial processes. This ability has already been turned to

industrial uses in terms of radiography, control instruments, and tracer systems.

Nonradioactive Isotopes

Most of the suggested potential uses for fission products are dependent upon the unique properties associated with their radioactivity. However, some consideration should be given to the possibility of using certain rare nonradioactive elements, which develop from the fission products, for their chemical and physical properties alone. Some of these stable elements (resulting from the decay of radioisotopes) could be separated from the radioactive fission products. The cost of the different stable isotopes would probably amount to hundreds or thousands of dollars per pound. It is possible, however, that profitable specialized uses could be found for them.

AVAILABILITY AND COST

Since an indication of the range of possible costs and availability of fission products is sufficient for preliminary industrial consideration of potential uses, an attempt will be made here to present rough cost estimates.

Supply

The amounts of fission products potentially available for industrial utilization far exceed presently foreseen demand. The Hanford Works has produced and stored fission products since beginning operations over six years ago. Millions of curies of fission products have been and are being produced. More than enough are in storage and after processing could supply potential users ten-thousand and even hundred-thousand curie quantities.

Cost

The cost to industry of fission products will tend to decrease as demand increases. However, sufficient demand must be foreseen to justify the expense of constructing and operating special facilities to prepare and distribute fission products. Since the cost of building and operating such facilities would vary only slightly with the amount of material processed, large quantities of fission products must be used to attain low unit cost for these radioactive materials.

It appears that the Commission may adopt the policy of regarding the cost of making fission products as marginal to its other operations. This means that no cost would be assigned to the raw gross fission products up to the point of processing for industrial distribution.

All costs of processing, shipping and handling made necessary by the fission products program would probably have to be paid for by the sale of these products, but the raw byproduct solutions might be free. Thus the cost of fission products in the various degrees of separation will depend on the aggregate amount of all products used, the demand for each specific group or class of products, and the processing necessary to produce the desired product.

Assuming a reasonably large demand, an estimate has been made of products that might be made available and their cost. The figure on page 5 classifies these fission products in groups of increasing process requirements. An estimated range of cost has been included as an indication of the possible price at which the products could be made available to industry.

The cost of separated fission products has been estimated over a very wide range because of the varying degree of difficulty in separating the individual products.

High purity isotopes, some resulting from small-scale processing of gross fission products, are presently being separated and sold by the Isotopes Division of the AEC. —END

Absolute Beta Counting at Defined Geometries

Reduction of calculations needed for absolute determination of disintegration rates of beta emitters is accomplished by standardizing geometry with a collimating orifice placed between the source and counter. An expression is given for approximation of beta-particle absorption. Results are cited

By G. I. GLEASON, J. D. TAYLOR and D. L. TABERN

Abbott Laboratories, North Chicago, Illinois

THE TRUE disintegration rate of a radioactive source can be related to the activity observed with an end-window G-M tube by a method known as "absolute beta counting." This method is based on geometrical, absorption, and scattering considerations of the counting arrangement rather than on a comparison with a previously calibrated standard.

A number of papers on absolute beta counting have already appeared in the literature. The work of Zumwalt (*1*) laid the foundations of the method and demonstrated the complexities involved. Sufficient data was presented by him to enable reasonably accurate determinations to be made after some individual counter characteristics had been evaluated. But the rigorous treatment described by Zumwalt has proved to be somewhat of a challenge, greatly discouraging wide use of the method.

Another paper by Burtt (*2*) gave an excellent exposition of some phenomena associated with absolute counting. The basic method, however, was not improved sufficiently to make it attractive for general use.

This paper describes an improved form of absolute beta counting. The technique is very simple in application and has provided acceptable results in most work. Essentially, it involves fixing the geometry of the counting arrangement so that this factor becomes independent of the Geiger tube. This is accomplished by means of a suitably machined orifice which, when properly placed between the source and counter, serves to collimate the counted beta particles into a defined geometric cone. The absorption factor has been empirically related to the maximum energy of the beta spectrum, and thus the disintegration rate can be calculated from an observed counting rate as

$$D = \frac{n}{G f_W f_B} \qquad (1)$$

where D = absolute disintegration rate in dpm, n = observed counting rate (corrected for coincidence loss, gamma contribution if present, and normal background) in cpm, G = physical geometry, f_W = mass absorption correction factor for air and mica window, and f_B = backscatter correction factor. It is assumed that the source is essentially weightless and that there are an insignificant number of beta particles scattered into the geometric cone from the air and support structures. The present counting arrangement makes possible this reduction of Zumwalt's original expression

$$D = \frac{n}{G f_A f_B f_H f_S f_W} \qquad (2)$$

where the additional correction factors are f_A for the scattering effect of air, f_H for scattering from counter supports and sample holders, and f_S for the mass of the source. These last three factors will be discussed after the experimental arrangement and computation methods are presented.

Geometry

The geometry G is defined as the percentage of the radiation that would enter the sensitive volume of the G-M tube from a given source position if other effects were negligible. Generally, it has been the practice to determine the geometry (or geometrical efficiency) by first evaluating the contributing functions and then, after counting a calibrated source, solving Eq. 2 for G.

Mathematical expressions relating the "ideal" geometry to certain boundaries are available (*1*, *2*, *3*). Unfortunately, these governing boundaries are not directly measurable and are poorly defined, so that any calculation based on them is merely a guided estimate. One such expression for the geometry of a point source is

$$G = 0.5\left[1 - \frac{h}{\sqrt{h^2 + r^2}}\right] \qquad (3)$$

where h is the distance from the source to the sensitive volume ($a + b$ in Fig. 1) and r is the radius of the cathode. Quite obviously, b, the distance behind the mica-window to the boundary of the sensitive volume cannot be measured directly. Furthermore, it must be assumed that the diameter of the sensitive volume is bounded by the physical dimensions of the cathode and that all of the volume is equally sensitive to an incident particle. It thus becomes apparent that if the physical geometry is to be calculated with any degree of certainty, something other than the tube will have to define the counter system.

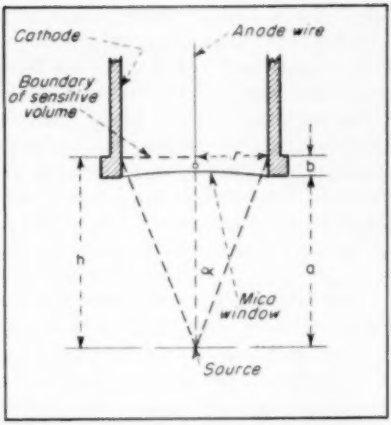


FIG. 1. Geometry offered by standard end-window G-M counting arrangement

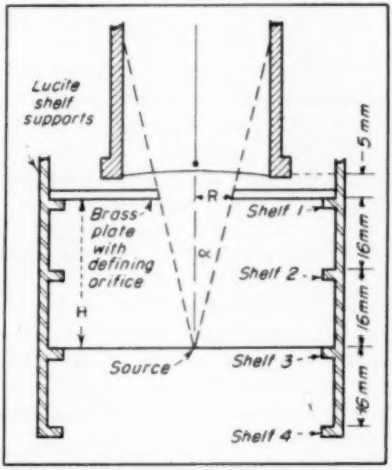


FIG. 2. Modified G-M counting arrangement employing defined geometry

The brass-plate collimator outlined in preceding paragraphs provides one means of defining the geometry. This same system was proposed and briefly described by Anger and Tobias (*4*) after the initiation of our project.

In our setup, a heavy brass plate having a machined hole coaxial with the anode wire of the counter is placed on shelf 1 of a sample and counter holder as shown in Fig. 2. The hole is some-

what smaller than the tube window, and any beta particles originating from a source on a shelf farther from the tube must penetrate to the very core of the sensitive volume. The brass plate is thick enough to absorb the incident particles completely, and the edge of the hole is bevelled at a predetermined angle so as to be parallel to the paths of the rays and thus reduce scattering. The tube then "sees" only that fraction of the beta particles admitted by the orifice and efficiently detects those having sufficient energy to penetrate the sensitive volume. The geometry of this arrangement is governed by the angle α which now can be expressed in terms of an H and R of real meaning

$$G = 0.5\left[1 - \frac{H}{\sqrt{H^2 + R^2}}\right] \quad (4)$$

To apply this method, particular care must be exercised with regard to dimensions. The safest approach is to prepare a scale drawing of the tube and source positions and select a brass-orifice size for shelf 1 such that the outermost particles from a point source on shelf 3 will intersect the cathode about 2 cm behind the mica window. In this manner, one is assured that all particles passing through the orifice will enter and travel a considerable distance in the "active" sensitive volume and, in so doing, increase the probability of producing a pulse.

In our particular counting arrangement, shelf 1 is 5 mm below the face of the tube and shelf 3 is 32.0 mm below shelf 1. By the method described above, it was determined that the diameter of the brass orifice should be on the order of 16 mm, the mica-window diameter being 27 mm. The angle α, or bevel of the brass orifice was calculated to be

$$\alpha = \tan^{-1} R/H = \tan^{-1} 8/32 = 14 \text{ degrees} \quad (5)$$

The finished brass plate has an orifice diameter of 0.6305 in. which provides an R of 8.007 mm. Using this value with an H of 32.0 mm in Eq. 4 gave a point-source geometry of 0.01497, or, in significant figures, 0.0150.

By differentiating Eq. 4 with respect to first H and then R, it was determined that the radius is the most critical value. An error of 0.1 mm in measuring R will introduce about a 2½% error in the geometry. The distance H would have to be 0.5 mm in error to produce a deviation of similar magnitude.

The thickness of our experimental brass plate was 1.6 mm, giving a mass per unit area of about 1,400 mg/cm². This is sufficient to absorb the 1.7-Mev beta particles of P^{32} completely and could probably be used with beta-emitters up to 3 Mev. A solid brass plate of similar thickness was also prepared so that a compensation could be made for radiations penetrating or originating in the brass.

To test the validity of the geometric effect, two other brass orifices of different diameters were prepared. A point source of P^{32} was then counted from both the shelf 3 and shelf 4 positions at the respective geometries offered by the three brass plates. Here, n/G should be constant since all other terms in Eq. 1 have been held constant (on each of the shelves).

The results of the experiment are tabulated in Table 1. With the exception of the largest orifice, used with the source on shelf 3, the n/G ratio was substantially constant within the statistical error of the counting. The decrease in the n/G ratio on shelf 3 is attributed to the failure of the tube to detect effectively all of the particles passed by the 0.7110-in. brass orifice, or more specifically, that the outer regions of the active sensitive volume had been contacted. The relatively constant n/G ratio obtained from shelf 4, where the beta beam is more collimated, seems to support this conclusion.

TABLE 1
Geometries Offered by Three Brass Orifices

Orifice diameter (*in.*)	*Source on shelf 3*			*Source on shelf 4*		
	G	n	n/G	G	n	n/G
0.5495	0.0115	2,722	237,000	0.00520	1,160	223,000
0.6305	0.0150	3,556	237,000	0.00686	1,520	222,000
0.7110	0.0186	4,291	228,000	0.00863	1,900	220,000

If the n/G ratio from shelf 4 is corrected for decay, for 16 mm of air absorption, and for floor contribution, the n/G ratio for shelf 3 is obtained. Thus, it is evident that the geometries of these arrangements have been rather accurately defined by the orifice dimensions and the source-to-orifice distances.

With the defining arrangement having the dimensions described, no appreciable error is introduced by neglecting the diameter of the source when it is less than 5 mm. In cases where the source had a significant diameter, geometries were calculated by means of the Blachman equation (*2*).

Absorption of Beta Particles

A certain fraction of the beta particles emitted from a given isotope will be absorbed by the mica window and air between the source and the sensitive volume. A great quantity of work has been presented on the interaction of beta particles with matter. As a result, the magnitude of the absorption has been shown to be dependent primarily upon the mass per unit area (mg/cm²) of the distance traversed and the maximum energy of the beta spectrum involved.

The factor, f_W, was introduced in Eqs. 1 and 2 to denote the correction that must be applied to a counting rate to convert it to that which would be observed if the air and window were absent. This factor is best approximated by preparing a plot of the aluminum absorption curve and extrapolating backward through the thickness presented by the air and window to zero (Fig. 3). This method can provide accuracy consistent with that of the rest of an absolute determination, although in the strictest sense it is not valid (*5*).

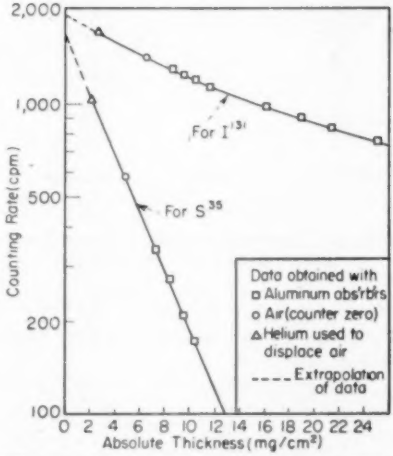


FIG. 3. Typical beta absorption curves

Unfortunately, the shape of an aluminum absorption curve is greatly dependent on the counting arrangement (*6*), and there is no accepted general curve for any isotope. The ideal results are obtained with the source at a considerable distance from the tube with the absorbers almost against the mica window. In this case, the curves will be almost linear

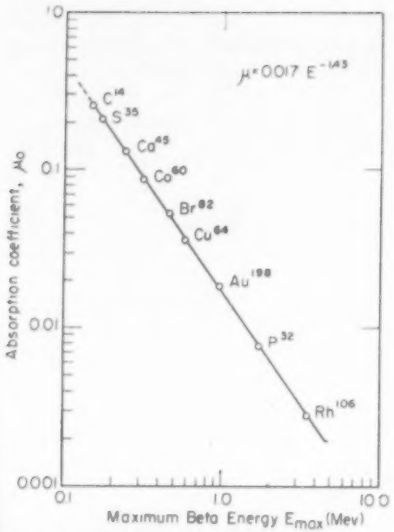


FIG. 4. Absorption coefficient as a function of maximum beta energy

on the semilog plot; toward the end of the range a concavity toward the origin will be observed.

The arrangement for providing a defined geometry offers a particularly stable system for studying aluminum absorption. In this case, an absorber placed on top of the brass orifice plate subtends the same solid angle as the geometric cone; interfering effects such as scattering are thus minimized. Curves from data so obtained show little departure from an exponential function over the first 10% or so of the range of a given beta emitter possessing only one maximum energy, E_{max}. The slopes of the curves are duplicated with remarkable consistency. The absorption can then be treated mathematically

$$n_t = N_0 e^{-\mu t} \qquad (6)$$

where n_t = corrected counting rate observed with thickness t between the source and sensitive volume, N_0 = true beta counting rate at zero thickness, μ = mass absorption coefficient in cm²/mg, and t = mass per unit area of the distance between the source and sensitive volume, in mg/cm². Since μ can be treated as a constant for a particular beta emitter, the correction factor, f_W, is directly obtained from

$$f_W = \frac{n_t}{N_0} = e^{-\mu t} \qquad (7)$$

The evaluation of μ requires that rather precise aluminum absorption curves be run on the particular isotope under study. Care should be exercised in preparing aluminum foils of known cross-sectional density which are free from wrinkles and thin spots. The source should be mounted on an essentially weightless backing; the spectrum of backscattered radiation is different from that of direct radiation, and an increased slope (and value of μ) may be observed.* From the completed plot, μ is calculated as

$$\mu = \frac{1}{\Delta t} \ln \frac{n_t}{n_{t+\Delta t}} \qquad (8)$$

where Δt = thickness of absorber, n_t = counting rate at thickness t, and $n_{t+\Delta t}$ = counting rate when the absorber thickness is $t + \Delta t$.

Absorption at low mass per unit area can be studied by enclosing the sample-holder supports and flushing out the air with helium. In our arrangement, this reduces the thickness from shelf 3 to the tube from 6.5 to 2.2 mg/cm².

By studying aluminum, air, and helium absorption curves for several beta-emitting isotopes, we have derived an expression which relates the mass absorption coefficient (at or near zero thickness) to the maximum beta energy through the range of 0.15 to 3.5 Mev†

$$\mu_0 = 0.017 E_{max}^{-1.43} \qquad (9)$$

where μ_0 is the mass absorption coefficient near zero thickness, and E_{max} is the maximum energy of the beta

* It should be pointed out here that the f_W correction should always be made with the values obtained with an unbacked source. The backscatter correction automatically reduces the counting rate to this condition.

† This expression does not appear to be as valid for spectra of the forbidden transitions such as that occurring with RaE.

TABLE 2

Calculated and Observed Absorption Corrections for Mass per Unit Area = 5 mg/cm²

Isotope	Beta E_{max}	Calculated μ	Calculated f_W	Observed f_W	Error (%)
C^{14}	0.154	0.26	0.272	0.272	—
S^{35}	0.170	0.21	0.350	0.348	− 0.57
Ca^{45}	0.250	0.122	0.543	0.545	+ 0.37
Fe^{59}	0.26(50%)	0.117	0.668	0.554	−17
	0.46(50%)	0.052			
Co^{60}	0.310	0.088	0.645	0.647	+ 0.31
Br^{82}	0.465	0.051	0.775	0.765	− 1.3
Cu^{64}	0.58	0.035	0.840	0.843	+ 0.35
I^{131}	0.600(85%)	0.035	0.811	0.792	− 2.3
	0.315(15%)	0.086			
Au^{198}	0.966(85%)	0.018	0.903	0.882	− 2.3
	0.601(15%)	0.035			
RaE	1.17	0.014	0.943	0.882	− 6.5
P^{32}	1.70	0.0078	0.962	0.962	—
Rh^{106}	3.55(80%)	0.0030	0.985	0.985	—
	2.8 (20%)				

spectrum in Mev. An expression similar to Eq. 9 for energies above 0.5 Mev has already been given (7). It uses different constants. Figure 4 shows a log-log plot of Eq. 9 with some of the supporting data.

In combination with Eq. 7, Eq. 9 makes approximation of the factor f_W possible, provided that the identity of the isotope (and E_{max}) is known. It does require, however, that only one E_{max} be present.

When absorption curves of isotopes exhibiting branched beta decay are examined, a decided increase in the slope near zero thickness is generally seen. This is caused by the softer component of the radiation being filtered out by the thin absorbers, leaving only the harder radiation to describe the remainder of the curve. If the observed curve is assumed to be a summation of two ideal exponential curves, a mathematical expression similar to Eq. 7 for this more complex system can be given

$$f_W = \frac{n_t}{N_0} = ae^{-\mu_1 t} + (1 - a)e^{-\mu_2 t} \quad (10)$$

where a is the fractional contribution of one component, and μ_1 and μ_2 are the ideal absorption coefficients for the two beta energies as given by Eq. 9.

It has been our experience that these calculated f_W values permit absorption corrections to be made with an accuracy at least comparable to the extrapolation of actual aluminum absorption curves, especially to those which are hastily made without due regard to statistics. In addition, great flexibility of the counting arrangement is realized.

Table 2 shows a comparison of calculated and observed extrapolation factors for a number of isotopes. The factors show what percentage of the beta radiation would penetrate 5 mg/cm² of material, a condition quite comparable to a counting set-up. The failure of Fe^{59} to conform is not immediately explained. A possibility that it was contaminated with Fe^{55} exists. The RaE beta spectrum, however, is known to be composed of a large fraction of low-energy particles; to this is attributed the steepness of the observed absorption curve.

For convenience, the data in Table 3 were calculated from Eq. 9 and Eqs. 7

TABLE 3
Calculated Absorption Corrections for Some Important Isotopes

Absolute thickness (mg/cm^2)	*Absorption correction factors for:*						
	P^{32}	Au^{198}	I^{131}	Co^{60}	Ca^{45}	S^{35}	C^{14}
1	0.992	0.980	0.960	0.916	0.885	0.811	0.782
2	0.985	0.960	0.918	0.839	0.784	0.657	0.595
3	0.977	0.940	0.881	0.768	0.694	0.533	0.458
4	0.970	0.922	0.844	0.704	0.615	0.432	0.354
5	0.962	0.903	0.811	0.645	0.543	0.350	0.272
6	0.955	0.885	0.779	0.590	0.482	0.284	0.211
7	0.947	0.867	0.747	0.541	0.427	0.230	0.163

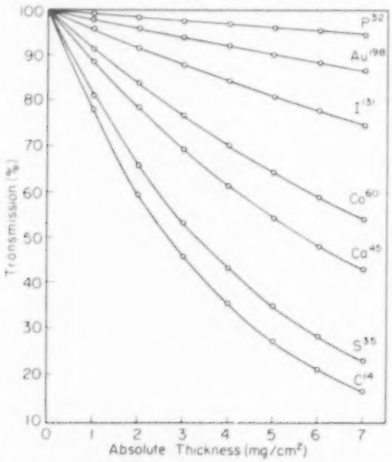


FIG. 5. Absorption of beta particles from some common isotopes

or 10. These can be transferred to a graph as in Fig. 5 for more accurate interpolation.

Backscatter Effect

Backscatter is somewhat analogous to reflection. A source supported by a finite thickness of material will show an increased counting rate because of this phenomenon. The correction factor f_B denotes that increase which will be observed using a given support as compared to the true counting rate. Values from near unity to about 1.8 are obtained for f_B, depending on a number of variables. Inadequate knowledge of this term can introduce pronounced errors in any absolute work.

Several investigators (*2*, *3*, *8*) have studied this effect with the goal of presenting backscatter data in a generalized form. While there is certainly a trend of agreement within these works, we felt obliged to employ "weightless" backings with contributions known to approach unity.

Polystyrene films 1-mil thick (about 2.5 mg/cm²) make excellent, easily constructed, and rugged mounts. Their backscatter contribution has been given as about 1% (*1*) regardless of the beta energy involved. When it is desired to use a thicker mount such as metal disks or cups, the operator is urged to conduct his own backscatter determinations. In addition, we recommend that this be done by actually applying identical aliquots to both metal mounts and films and calculating f_B as

$$f_B = \frac{\text{cpm on metal}}{\text{cpm on film}} \quad (f_B \text{ of film})$$

This treatment is valid except when the film is placed near the floor of the counter support (*2*).

Scattering Factors

The increase in counting rate caused by scattering from the support structure (other than the mount and floor of the counter) is denoted by f_H. Even with

the mica window fully exposed (not masked) the contribution of the vertical Lucite slotted supports is negligible (*2*). The insertion of the defining brass orifice on shelf 1 serves to reduce this already negligible quantity since the scattered particles are traveling at such oblique angles that they are not likely to pass through the brass orifice and the mica window on the same path.

The question has been raised as to possible scattering effects on the wall of the orifice itself. The hole was bevelled to avoid this, and all the evidence seems to indicate that no significant contribution is produced.

The increase in counting rate due to scattering of beta particles by the air is denoted by f_A. The work of Zumwalt (*1*) with fully-exposed mica windows has shown that the magnitude of this term is only appreciable when soft radiation is traversing a considerable air distance. This condition should be avoided to circumvent absorption effects alone, if not to decrease air scattering. For calibrating S^{35} and C^{14}, we have prepared a condensed version of the method, employing an aluminum orifice of smaller dimensions and placing the source on shelf 2.

The combined effects of self-absorption and scattering is denoted by the factor, f_S. This term becomes significant in the case of soft radiation from a source of appreciable mass. In this work, only weightless sources were used, and f_S was considered as unity. In the event that this phenomonen must be considered, adequate methods have been given in the literature (*9*).

Tube and Circuit Efficiencies

Losses caused by the finite resolving time of the G-M tube and scaling circuit (mechanical register) are readily determined. By the method of paired sources (*3*), the dead-time of the tube used in this work was found to be 100–120 μsec. For a tube having such rapid recovery, coincidence corrections are very small for counting rates up to 5,000 cpm. Actually, we prefer to avoid coincidence by making suitable dilutions of the activity so that the counting rates are limited to the region of 2,000 cpm.

The success of the method depends very much on the Geiger tube itself. It should have a thin window (less than 2 mg/cm^2) and good characteristics, i.e., a 300-volt, 1%-per-100-volt plateau. This requirement obviously eliminates the use of infinite-life halogen-quenched tubes having a 7% plateau. While most organic quenched tubes have been found to be satisfactory, the best results have been obtained with those having a slightly greater cathode diameter than window diameter.*

These particular tubes can be exchanged in a defined geometry set-up with a standard source with as little as 1% variance. This, in fact, should be the test conducted on a new tube to check the sensitivity and adaptability to defined-geometry counting.

Of particular concern in absolute beta counting is the day-to-day variation in the G-M tube sensitivity. With our equipment in an air-conditioned room, we have observed open-tube variations on the order of 3–4% on occasions when counting a RaDEF standard. This is striking since the average deviation over weeks of counting was about 1%. It is of interest to point out that the greatest variations occurred when the tube and scaling circuit had not been in operation very long.

Apparent stabilization of the G-M tube is achieved when the brass orifice plate is inserted. The counting rate of the RaDEF standard under these conditions is much more constant and seems to be less dependent on the warm-up time. This is believed to be

* Tracerlab TGC-2 and Radiation Counter Laboratories Mark 1 Model 3 G-M tubes gave good results.

due to the fact that only the core of the sensitive volume is being utilized.

Comparative Calibrations

The following example, in which the disintegration rate of a National Bureau of Standards I^{131} standard was checked, serves to demonstrate the practical nature of the method.

The solution as obtained from NBS was pipetted in 10λ(0.010 cm³) portions upon polystyrene mounts, treated with dilute silver nitrate solution, and dried under an infra-red lamp. These samples were then counted under a defined geometry as offered by the arrangement shown in Fig. 2. Since the dried mounts had a diameter of 8 mm, the first three terms of the Blachman series (*2*) were employed in the geometry calculation. This gave a resultant geometry of 0.01478, a little over 1% lower than the geometry of 0.0150 given by Eq. 5 for a point source. For our calculations, we used $G = 0.0148$.

The mass of air and mica-window between the activity and the sensitive volume was estimated at 6.5 mg/cm². The absorption factor, f_W, was calculated as follows (*11*):

$E_{max} = 0.60$ Mev $\quad (a = 85\%)$

$\mu_1 = 0.035$ (Fig. 4)

$E_{max} = 0.315$ Mev $\quad (1 - a = 15\%)$

$\mu_2 = 0.088$ (Fig. 4)

From Eq. 8

$$f_W = ae^{-\mu_1 t} + (1 - a)e^{-\mu_2 t}$$
$$= 0.85e^{-0.035(6.5)} + 0.15e^{-0.088(6.5)}$$
$$= 0.85(796) + 0.15(565)$$
$$f_W = 0.763$$

Averaged estimates on carefully prepared aluminum absorption curves gave an extrapolation factor through 6.5 mg/cm² of 0.742 (a difference of about 2.8%). The backscatter contribution of the polystyrene film was considered to be 1.013 (*10*).

The absolute disintegration rate was calculated in millirutherfords/cm² from Eq. 1

$$D = \frac{n}{GfwfB}$$
$$= \frac{n}{0.0148(0.763)(1.013)} \times \frac{10^2}{60 \times 10^3}$$
$$= \frac{n}{6.86} \text{ mrd/cm}^2$$

The average counting rate of the mounted samples, corrected for background and gamma contribution, was 217 cpm; the reliable error was 1%. With the decay of 13.44 days which had taken place, the decay factor was 0.312. Thus,

$$D = \frac{217}{6.86(0.312)} = 101.3 \text{ mrd/cm}^2$$

TABLE 4
Absolute Values Obtained For Some Isotopes

Isotope	E_{max}	*Calibration*		*Calibrator and method*
		This work	*Other*	
I^{131}	0.600 0.315	101.3 mrd	100 mrd	NBS† Coincidence
P^{32}	1.70	327 mrd	328 mrd	NBS 4π Counter
Co^{60}	0.310	140 mrd	159 mrd	NBS Coincidence
RaE	1.17	514 μrd*	505 μrd	NBS Ra content
Au^{198}	0.966 0.60	2.55 mc	2.55 mc	ORNL‡ Ion-chamber
S^{35}	0.17	2.62 mc	2.71 mc	ORNL (unknown)

* True absorption curve for RaE used for extrapolation and 8% added for self-scatter (*2*).
† National Bureau of Standards, Washington, D. C.
‡ Oak Ridge National Laboratory, Oak Ridge, Tenn.

The value obtained by NBS using the coincidence counting method was 100 mrd/cm³ with an error which was estimated to be ±3%.

In a similar manner, an NBS solution calibrated by the 4π counting method as 327×10^3 dps/cm³ gave 328×10^3 dps/cm³ when examined with the defined-geometry procedure. Intercomparisons on materials received from the Isotopes Division of the Atomic Energy Commission, Oak Ridge, Tenn., have been generally favorable (*11*). These have included I^{131}, P^{32}, Au^{198}, Co^{60}, S^{35} and Ca^{45}. Thus, under the conditions described, even the absolute disintegration rate of soft beta emitters can be satisfactorily approximated. A comparison with some of the other methods is given in Table 4.

We wish to express our appreciation to Mary Savoie for her assistance in the preparation and counting of samples.

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Decontamination of Small Volumes of Radioactive Water*

A simple apparatus capable of reducing the activity level of water from 2.5 to $<10^{-4}$ μc/ml is described. Experimental results indicate it could be used successfully, following an atomic attack, to treat emergency water supplies

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IT HAS BEEN FOUND possible to decontaminate highly radioactive water to a level well below the emergency concentration permissible for drinking water, with a compact unit constructed of readily available materials.

Water in which radioisotopes resulting from fission had been mixed has been processed to give a product containing less than 10^{-4} microcuries of activity per milliliter, a concentration presenting little biological hazard. It is some one hundred times less than the maximum permissible concentrations of the order of 10^{-2} μc/ml that have been

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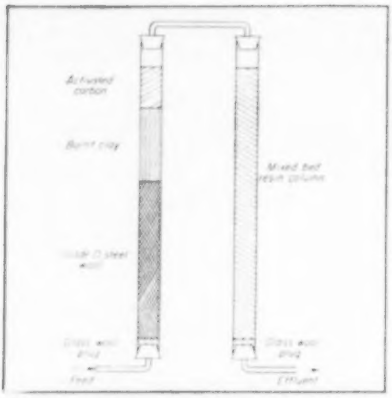

FIG. 1. Typical experimental unit for treating radioactive water

suggested (*1–3*) for both alpha and beta contamination as acceptable for emergency use for a period of from one week to ten days.

Although the experimental work is not yet completed, the interest shown in the development has prompted this progress report on the work to date.

The treatment found to be most effective consists of passing the water through the following materials, arranged in series: steel wool, burnt clay, activated carbon, and a mixed bed of ion-exchange resins. A typical test apparatus is shown in Fig. 1.

Two columns, each 26 inches in length by ¾ inch in diameter, were arranged so that the feed passed upflow through the first section and downflow through the second.

The first section contained 50 grams of grade 0 steel wool packed into 15 inches of column length, 37 grams of calcined clay packed into 8 inches, and 12 grams of activated carbon packed into 3 inches.

The second section of the unit was packed to a depth of 26 inches with a mixed bed of quaternary aminepolystyrene (strong base) type anion exchange resin and nuclear-sulfonic polystyrene (strong acid) type cation exchange resin.

The feed used was prepared by diluting a 60-hour-old solution of fission-product mixture with tap water to give a final concentration of radioactivity of approximately 2.5 μc/ml of feed. Since the stock solution was highly acidic, it was evaporated to dryness to expel most of the acid. The feed was adjusted to the *p*H of tap water (7.5) with NaOH. Table 1 shows an ionic analysis of the Oak Ridge tap water used to prepare the feed solutions.

The feed did not contain the fission products in the same ratio as would be found following a bomb blast, but did contain portions of all the radioisotopes that would be present. The results obtained were, therefore, thought to be representative of the decontamination that could be obtained under actual emergency conditions resulting from a bomb burst or direct contamination with fission products.

TABLE 1
Ionic Analysis of Feed Water
(*p*H = 7.5)

Constituents	*Concentrations (ppm)*
Ppn. alkalinity as $CaCO_3$	2
Methyl orange alkalinity as $CaCO_3$	90
Soap hardness as $CaCO_3$	90
Dissolved CO_2	3
Dissolved solids	120
Nonvolatile solids	80
SiO_2	6
Ca	25
Mg	8
Na	6–8
SO_4	30
Cl	6
CO_3	54
HCO_3	115

Factors Studied

The effect of flow rate, the effect of resin-bed depth, the efficiency of the resin if used alone, and the effectiveness of each component as used in the

apparatus were among the factors studied.

The endpoint for each run was arbitrarily taken to be that volume at which the activity in the effluent exceeded 10^{-4} μc/ml.

Flow rates varying from 0.4 gal/min/ft² of bed area to 5 gal/min/ft² were used. Over this range, neither the efficiency of removal nor the total capacity of the unit was affected. The indication was that even higher flow rates could be employed.

The effect of the resin-bed depth is illustrated in Fig. 2. In this test, a flow rate of 2.95 gal/min/ft² was used with a feed containing approximately 2.5 μc/ml of radioactivity. It can be seen that the volume of water which can be treated before the effluent activity exceeds any given quantity is almost directly proportional to the total volume of resin used. This suggests the possibility that extremely small units could be employed in those cases in which it would be necessary to treat only a small volume of water. As yet, no investigation has been made with columns having bed depths of less than 13 inches.

Figure 3 shows the activity in the effluent from a resin column only and that from an identical resin column used in conjunction with the steel wool, clay, and carbon. Leakage from the resin column when used alone was almost immediately apparent, with the endpoint of 10^{-4} μc/ml (~10 cpm/ml) being exceeded at about 3 liters.

With the complete assembly, 28 liters were processed before the effluent activity exceeded 10^{-4} μc/ml. At 25 liters, the resin column alone had broken completely, whereas at the same volume the effluent activity of the complete unit was still considerably less than 10^{-4} μc/ml, although a gradual breakthrough was beginning to take place. The activity of the effluent increased slowly until, at about 40 liters,

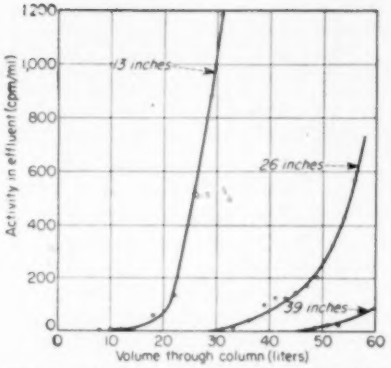

FIG. 2. Activity of effluent as function of volume for different exchanger bed depths

the activity leveled off at about 5×10^{-4} μc/ml, lower than the emergency maximum permissible concentration by a factor of twenty.

Up through about 28 liters, the effluent was essentially deionized with a *p*H very nearly 7.0. As the activity began to increase, a simultaneous drop in the *p*H occurred and a small amount of solids was found in the liquid. This is to be expected as the resin bed becomes depleted. The *p*H of the effluent at 40 liters was about 4.3.

The absence of a sharp breakthrough

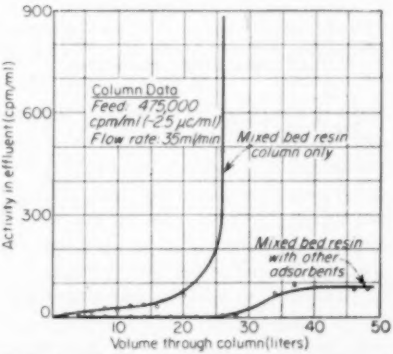

FIG. 3. Effluent activity as a function of volume for ion-exchange column only and for complete unit

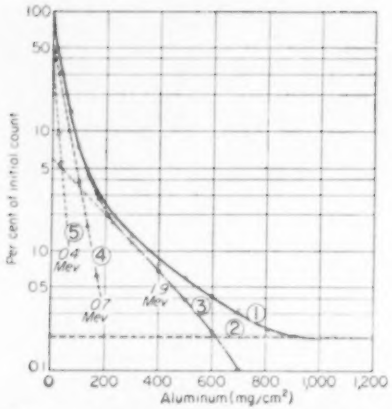

FIG. 4. Aluminum absorption curve of a one-liter fraction of the effluent taken after 29,000 ml had passed through column

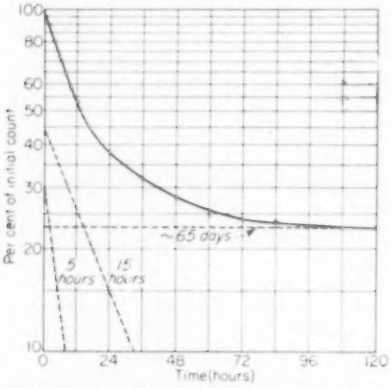

FIG. 5. Decay curve of a one-liter fraction of the effluent taken after 29,000 ml had passed through column

with the combined assembly can be attributed to the effectiveness of the steel wool, clay, and carbon in removing radio-ions that normally leak through the mixed-bed resin column and to the continued adsorption of cations of higher valence by the cation resin.

The identity of the active emitters in the effluent from the column has not yet been established. It has been determined, however, that the major portion of the radioactivity has relatively low energies and fairly short half-lives. Analysis by the standard methods for absorption and decay curves* of a concentrated, one-liter fraction of the effluent taken after 29,000 ml had passed through the column indicated that at least three components were present. The aluminum adsorption curve (Fig. 4) shows that of the total effluent activity about 6% has an energy equal to approximately 1.9 Mev, 56% an energy of 0.7 Mev, and 38% an energy of approximately 0.4 Mev. The curve also shows the presence of a small amount of gamma radiation.

A decay curve (Fig. 5) of the same fraction indicates the presence of isotopes with half-lives of 5 hours, 15 hours, and approximately 65 days. That portion of the radioactivity with a half-life of only 5 hours is thought to be due to the daughter product of a longer-lived isotope; otherwise, it would not be found in the 60-hour-old mixture (after 10 half-lives have elapsed, the radioactive element may be considered as having decayed completely). The 15-hour component may possibly be a daughter product also, but could as easily be a parent isotope which would still be present, having passed through only four half-lives.

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* References to this method of analysis may be found in the literature (*4, 5*). It involves counting the sample a number of times, once with no absorber and then with different thicknesses of aluminum interposed between sample and counter. The data when plotted resemble curve 1 in Fig. 4. The fraction of the curve due to gamma radiation (curve 2) is subtracted from curve 1 to obtain an absorption curve for beta radiation alone (curve 3). The straight portion of curve 3 is extrapolated to zero absorber. The slope of this line determines the half-thickness (the weight of absorber necessary to reduce the counting rate by half) of the component with the highest energy. Half-thickness, in turn, is a measure of the energy of the emitted radiation of that component. The intersection of the extrapolated line with the zero axis indicates the per cent of the total radiation from the sample that is due to the component with that energy.

By successive subtractions, curves 4 and 5 can be obtained. The method is only approximate and decreases in accuracy as the number of components increases.

The decay curve (Fig. 5) was analyzed in the same manner, except that the half-lives of each component are read directly from the figure.

A further analysis, radiochemically, showed the presence of less than 2×10^{-7} μc/ml of strontium, which includes one of the more dangerous radioisotopes from the standpoint of biological hazard.

Alpha activity was not detected until after the beta activity of the effluent exceeded 10^{-4} μc/ml. At 36 liters, an evaporated sample showed 0.07 cpm/ml of alpha activity. It is believed, therefore, that the effluent activity is biologically unimportant, since the half-life is short, the average energy is low, and no alpha is present.

Actions of Materials Used

The efficiency of the steel wool in removing fission products from water is easily seen from the data given in Table 2. It shows the results of radiochemical analyses made on the activity eluted from each component following one of the tests. This test was run using a fission-product solution about one month old; consequently, the efficiencies shown are for the isotopes of longer half-life.

The table shows that 85.3% of the radioactivity was taken out by the steel wool, 12% by the clay, 0.8% by the carbon, 1.9% by the cation exchangers, and 0.2% by the anion exchanger. The remainder of the table shows the percentages of specific isotopes on each of the components. With the 60-hour-old mixture of isotopes, the steel wool accounted for about 86.3% of the total radioactivity, the clay and carbon combined for 2.5%, and the mixed-resin bed for about 11.3%.

The actions of all the materials em-

TABLE 2

Radiochemical Analysis of Activity Adsorbed by the Materials in the Decontaminato

Isotope	*Steel wool*	*Burnt clay*	*Activated charcoal*	*Cation resin*	*Anion resin*
Total beta cpm	2.35×10^{9}	3.3×10^{8}	2.21×10^{7}	5.28×10^{7}	5.87×10^{6}
% of total beta	85.26	11.99	0.80	1.92	0.21
Ruthenium cpm	4.43×10^{7}	1.67×10^{6}	6.53×10^{4}	8.89×10^{4}	4.0×10^{4}
% of total Ru	95.96	3.62	0.14	0.19	0.09
Zirconium cpm	1.72×10^{8}	7.37×10^{5}	1.05×10^{5}	1.87×10^{5}	3.06×10^{4}
% of total Zr	99.39	0.43	0.061	0.108	0.018
Strontium cpm	3.19×10^{8}	8.36×10^{7}	1.63×10^{7}	3.83×10^{7}	3.69×10^{5}
% of total Sr	69.72	18.27	3.56	8.37	0.81
Rare Earths* cpm	1.54×10^{9}	2.31×10^{8}	1.64×10^{6}	1.21×10^{6}	5.94×10^{4}
% of total R.E.	86.81	13.02	0.09	0.06	0.003
Cerium† cpm	6.81×10^{8}	1.99×10^{7}	2.34×10^{4}	1.51×10^{5}	1.36×10^{4}
% of total Ce	97.13	2.84	0.003	0.02	0.002
Cesium cpm	2.39×10^{6}	1.60×10^{6}	None found	5.72×10^{3}	5.06×10^{2}
% of total Cs	59.74	39.99	0.0	0.14	0.13
Niobium cpm	6.99×10^{6}	4.10×10^{4}	8.25×10^{2}	3.12×10^{4}	1.14×10^{4}
% of total Nb	98.7	0.58	0.12	0.44	0.16
Tellurium cpm	1.15×10^{7}	1.05×10^{5}	2.3×10^{4}	2.77×10^{4}	3.87×10^{4}
% of total Te	98.34	0.89	0.19	0.237	0.331

* Total rare earths
† Cerium is also included in total rare earths

ployed in the unit have not been established.

The steel wool was added primarily to remove ruthenium, for which it had been found to be very effective, and possibly other noble metals. Its effectiveness in removing the large percentages of other isotopes was not expected. The hypothesis has been advanced that the steel wool serves as a reducing agent, with a subsequent plating taking place, and as a medium for the adsorption of radiocolloids, many of which exist at the *p*H of the tap water used. It was found to be impossible to remove the activity by washing with water, ruling out the possibility of floc filtration. The radioactivity, however, can be removed with diluted HCl, thereby preparing the steel wool for reuse.

During the operation of the column a band of rust appears at the bottom of the column, due to the oxidation of iron by the air in the water. No difficulty was experienced from this, however, as the rust band moved very slowly up the column.

It was found that plugging of the column occurred when fine iron filings were used in place of the steel wool or when an extremely fine grade of steel wool was used. It should be possible to use a coarse grade of iron chips, or possibly another metal in granular form, with greater ease in packing.

The burnt clay had been found, through tracer runs with both natural and prepared earths, to be highly efficient for the adsorption of cesium, and to a lesser extent, for strontium. In addition it serves as a filter and adsorbent for the small amount of iron that dissolves from the steel wool.

The carbon was added primarily for taste, color, and odor control and also for removal of small quantities of radioactivity.

A number of ion-exchange resins are available which will serve equally well in the unit. In general, these should be of the strong-base and strong-acid types for the greater salt-splitting effect and faster reaction times obtainable.

* * *

The authors are indebted to the Permutit Company, New York, N.Y., the Rohm and Haas Company, Philadelphia, Pa., the National Aluminate Corporation, Chicago, Ill., and the Dennison Manufacturing Company, Asheville, N. C., which furnished samples of materials and to ORNL personnel who contributed to the work reported here.

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"When one considers, on the one hand, the enormous complexity of the problem of making a comprehensive forecast of the economic consequences of atomic power, and, on the other hand, the undeveloped character of the economists' analytical tools for making such a forecast, it is something of a relief for an economist that we don't yet know what atomic power will cost. For, if we did know, it would be only because an atomic power plant were in existence and about to produce the economic effects which we are not equipped to predict."

—*Joseph E. Loftus*, Bulletin of the Atomic Scientists, *March, 1951*

Decontaminable Surfaces for Millicurie-Level Laboratories

Here are the results of an engineering investigation into methods of achieving decontaminability of surfaces fabricated from materials commercially available at moderate cost. Engineers and architects, and the scientists working with them, will want to consider the specific suggestions offered

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THE PRINCIPAL FUNCTION of decontaminable surfaces is to permit safe, economical and efficient isolation and removal of stray active materials before they can become dispersed or lodged in permanent structural members. Appropriate use of such surfaces decreases hazards to personnel, produces long-term savings in decontamination costs, and improves experimental precision by preserving low-background radiation values and preventing cross contamination.

In the literature, some general types of materials for decontaminable surfaces are suggested as applicable to individual conceptions of laboratory design (*1–10*). Extensive tests on particular surface materials have also been reported (*11–13*). The present article has been made more specific in individual surface selections.

Based both on experimental studies and surveys of existing facilities made in connection with the design of several new radioactivity laboratories, it is limited to consideration of methods for achieving decontaminability of surfaces in laboratories handling low (millicurie) levels of activity. Waste disposal, general layout, and the other aspects of laboratory design are not discussed.

Many of the suggestions made here are not original but have been chosen as especially suitable; in some cases other choices might also prove wholly adequate. The present selection attempts to provide for a good quality, fireproof laboratory of long, useful life expectancy at a minimum over-all cost and includes only a few products of non-standard design.

Suggestions are presented for floor coverings, walls and ceilings, bench tops, paints, strippable coatings, sinks and drainage systems, hoods, ducts, crack-sealing materials and other items peculiar to the radioactivity laboratory.

Some of the important requirements of each kind of laboratory surface are pointed out in individual items below and the characteristics of several representative examples are discussed.

There are two main schools of thought concerning decontaminable surfaces. One favors use of cheap materials whose frequent discard and replacement would not entail great expense; disposable surfaces designed to absorb contamination have also been recommended. The other favors impervious surfaces which can be cleaned and reused many times before disposal is necessary. In the case of

replaceable material, the initial capital cost should be lower and replacement costs probably higher. For reusable surfaces, a higher initial cost would be somewhat offset by less frequent replacement, provided the net cost of decontamination did not prove to be the controlling factor. This study attempts to combine the best features of each approach.

Flooring

Choice of suitable flooring material is determined almost as much by the general considerations of economics, ease of installation, service, maintenance, and effect on personnel, as by any special requirements imposed by radioactivity. It has been assumed here that a laboratory designer would already be familiar with basic flooring principles.

The main radioactivity considerations, then, may be summarized briefly as follows:

Installation. Any special techniques, such as the application of impervious membranes beneath the flooring, must be fairly conventional in nature and attainable with existing types of equipment if average contracting labor is to be employed and if initial costs are to be kept within reasonable bounds.

Service. A flooring should have a good wearing surface that does not shrink or buckle and should possess resistance to penetration or deterioration through the action of commonly encountered reagents and solvents. To allow easy cleaning and prevent radioactivity from contaminating the subfloor or foundation, it should also have as few open joints or cracks as possible.

Decontamination. The flooring surface should, insofar as is feasible, be decontaminable by means of mop-up techniques plus either washing or scrubbing with cleaning agents such as detergents, specific solvent or chemical action plus scraping, or wet-abrasion carefully controlled so that a dust hazard is not created.

Replacement. Contaminated areas of flooring that cannot be cleaned should be easily replaceable without generating dust or fumes, consuming an excessive amount of time and disturbing work in progress, or leaving a floor which is less resistant to future contamination.

The cost of replacement of contaminated areas, as derived from a consideration of the probable frequency of spills and the availability of crew and equipment for the repair work, should not be excessive.

Disposal of contaminated flooring by incineration is desirable.

Continuous Floorings

This group of essentially crack-free flooring materials includes trowel-on mixtures of mineral aggregate with suitable binders such as oxychloride cements, asphalts, synthetic rubbers or plastics. Also in this category are concrete, which has received some particular surface treatment to harden or "densify" it, and welded metal sheet or plate stock. While some of these materials may be used justifiably in particular areas where specific characteristics, such as great load resistance, make their use necessary, for general laboratory applications many have been found to be too porous or troublesome to replace.

The chemical resistance offered by some metallic surfaces, such as stainless steel, makes them worthy of consideration for areas with an especially high probability of frequent contamination. However, a metallic flooring surface

would be very expensive and would create a hazardous condition because of its slipperiness unless it were indented, in which case it would be hard to clean.

A few of the trowel-on mixes can be removed with some difficulty by the use of suitable solvents or heat, without creation of a dusty atmosphere.

Of the many continuous floorings which have been examined, one particular type appears to possess desirable qualities, although sufficient user history is not yet available on which to base a final judgment. It consists of a silicious aggregate in a neoprene latex binder, troweled onto a concrete floor to a thickness of approximately ⅛ inch and then surfaced with at least five sprayed coats of an aqueous dispersion of a vinyl plastic. A drying time of two to four hours is allowed between coats. The resultant top surface is tough and resistant to reagents. At the same time, it may be scored and peeled from the somewhat resilient base coating in the event that excessive contamination makes that step necessary. If the neoprene-type subcoating is used, the applied cost in large areas is about one third greater than for the best grades of asphalt tile. However, it should prove possible to reduce this cost by applying the vinyl emulsion directly to concrete that has been given a special primer to promote satisfactory adhesion.

Semicontinuous Floorings

This class of floorings includes linoleum, coated asphalted felts and papers, and solid rubber or vinyl sheeting.

The coated asphalt felts and papers are thin and quite readily indented, their virtue being a relatively low cost.

Linoleum has been used with some success in radioactivity laboratories, but it requires considerable maintenance and has relatively poor resistance to many chemicals and to the damp conditions of grade concrete.

Rubber is, in general, a satisfactory flooring material.

Vinyl materials are the most generally resistant to laboratory reagents and have been found easier to decontaminate in practice than, for example, linoleum. In addition, they are easily cleaned and do not require waxing; hence, there is no tendency for contaminated wax to be tracked from the laboratory. The tendency of vinyl flooring products to shrink noticeably with age has detracted greatly from their desirability in the past; however, there is recent evidence that some of the manufacturers have minimized this effect. The user history of these new vinyls is unfortunately too short to be reassuring, but the advantages of the material may in some cases make the risk of shrinkage worth taking.

The applied cost of ⅛-inch, heavy-duty linoleum should be somewhat lower, while that of a vinyl and rubber sheeting of comparable thickness should be equal to or slightly greater, than the figure for the best grade of greaseproof asphalt tile in $\frac{3}{16}$-inch thickness, depending on the size of the installation and cost of the contractor employed.

The main disadvantage of these semicontinuous flooring materials arises from the tendency for their customary adhesives to deteriorate through contact with moisture. As a consequence of this, most manufacturers at present will not guarantee their floorings for application to on- or below-grade concrete. Their use with water-resistant adhesives in such a situation would have to be as an acknowledged risk and would require such additional foundation waterproofing procedures as were deemed necessary to meet the prevailing ground-moisture conditions.

Tile Floorings

These floorings are made in a variety of materials. Some of them are cut from semicontinuous sheet flooring

stock such as vinyl, rubber, or linoleum. The general advantages and disadvantages of these materials in sheet form have been noted above.

Other such floorings are fabricated only in the form of small units such as ceramic and asphalt tiles.

Objections to ceramic tiles, aside from cost, are their porosity and the porosity of the joints, the difficulty of removal, and, in the case of glazed materials, the slipperiness.

Asphalt tile has the distinct advantage of being specifically recommended by manufacturers for on- or below-grade concrete flooring installations. It is obtainable in several types which vary somewhat in resistance to chemical reagents and solvents. The so-called greaseproof asphalt tile is resistant to oil or greases, but is not as resistant to most solvents as a vinyl or rubber flooring.

One of the main objections raised against all tile floorings in the past has been the large number of cracks associated with this type of installation. Certainly, open cracks are undesirable in the flooring of a radioactivity laboratory. Asphalt tile, however, tends to cold-flow under traffic and to seal many of the cracks after a few months of use.

If the tile is properly chosen for square edges and corners and is carefully installed and maintained, the probability of radioactive material finding its way into cracks can be minimized. The problem can be further diminished by using tiles of large size and by taking particular pains to seal the cracks. Possible crack-closing techniques involve initial heavy waxing and buffing off of the excess, sealing with special compounds or penetrants, or even sealing by thermal methods. The cost involved in the last two techniques would, however, probably limit their use to small areas of a large installation.

Although replacement of sections of the semicontinuous flooring discussed earlier is feasible by "double cutting" techniques, tile flooring has the advantage that in the event of severe contamination or damage, a section can be softened with the aid of an infra-red lamp, and easily removed; new tile can then be laid without marring the appearance of the entire flooring installation.

Suggestions—For above-grade, millicurie-level radioactivity laboratories, a satisfactory flooring is a $\frac{1}{8}$-inch-thick high-quality sheet vinyl or rubber product.

A vinyl or rubber sheeting might be used in on-grade installations as a calculated risk if a low water transmissivity for the concrete is assured and a waterproof adhesive is employed that has been shown to retain its bonding strength under moist conditions for a long period of time. A permanently tacky cut-back asphalt cement has given good results so far in one set of tests with vinyl flooring. To prevent trapping of solvent vapors, the cement was allowed to dry 24 hours before laying the flooring.

The waterproofing of concrete may take the form of surface treatments with pore-closing materials or, in many cases, it may even entail a water-tight system of interlayers of asphalted felt and hot-mopped asphalt between concrete slabs. The probable result of a damp foundation under a vinyl or rubber installation in use would be deterioration of the adhesive and lifting of the flooring.

For an above-grade installation, a high grade of $\frac{1}{8}$-inch battleship-type linoleum can be employed as an alternative to vinyl or rubber sheeting, at a moderate saving in initial cost. However, the necessity for frequent waxing is a deterent because of the maintenance cost and dust hazard.

For an on-grade situation where a guaranteed installation is desired, the most satisfactory flooring seems to be carefully installed $\frac{1}{8}$ or $\frac{3}{16}$-inch thick high-grade greaseproof asphalt tile

which has received a liberal initial coating of emulsion wax. The wax must be well buffed to drive it into the cracks. The necessity for periodic waxing of asphalt tile is dictated mainly by laboratory practices concerning workers' shoes, vehicle treads, etc. If a non-greaseproof grade of asphalt tile is used to achieve greater initial economy, care should be taken to provide trays for equipment such as vacuum pumps that might spill oil onto the floor.

For special cases of expected frequent contamination, an installation which should also prove satisfactory for on-grade concrete would be asphalt tile, preferably of greaseproof grade, that has been over-laid in the areas most subject to contamination with a strip of relatively inexpensive $\frac{1}{32}$-inch vinyl sheet surfacing material. The vinyl material is held in place by a pressure-sensitive "stripping" adhesive, such as a solution of polyisobutylene in Varnish Makers & Painters Naphtha. In the event of excessive contamination, the thin vinyl surface can readily be removed and replaced without damage to the asphalt tile. Care is required to prevent exposure of the adhesive at the edges of the sheeting.

Where the extra expense was warranted, protective membranes of copper, usually laminated to asphalt-impregnated paper, have been used between the flooring and the base concrete, with cut-back asphalt cement as a moisture and contamination barrier.

Wall and Ceiling Surfaces

In general, the requirements imposed by radioactivity on the choice of vertical and ceiling surfaces for a laboratory handling low-level radioactivity are almost identical with those already mentioned in some detail for flooring. But other considerations are pertinent.

Wall and ceiling surfaces should be smooth, crack-free, nonporous and, preferably, constructed so that sections of them can be readily removed without damage to the basic building structure and without hazard to the handling personnel. This eliminates from consideration many conventional construction forms such as lath and plaster.

Modern laboratory design has introduced the so-called module concept to allow flexibility in space and utilities. This has been accomplished in part through the development of demountable wall panels and perforated ceilings through which a portion of the ventilating air may enter. These panels are well suited for the radioactivity laboratory. They offer flexibility and ease of demounting and removal. Individual panels can be reused following successful decontamination. Since it is not necessary to saw, drill or perform other mechanical operations to remove the panels, there are no chips or dust to spread contamination. Each face of a wall section may be separately removed so that demounting a panel in one laboratory does not disturb the operations in the next.

Some basic panel materials are painted mild steel, stainless-steel-faced plywood, and transite. From considerations of cost and the requirements named, the first two types of material have been found to possess very satisfactory characteristics.

Suggestions—A stainless-steel, thin-plywood-laminate panel provides the corrosion resistance of stainless steel at a cost lower than that of coated mild steel panels. It can also be made lighter in weight and will occupy slightly less volume than an all-steel panel in the event of the necessity of ultimate disposal by incineration. The

wooden portions can be flame-proofed. It requires a slight amount of carpentry for installation. Installed cost for a two-sided panel is reported to be about two thirds that of the highest grade of comparable specially designed painted mild steel partitions, whose cost may run as high as three times that of a simple lath and plaster wall.

Despite their somewhat higher cost, double-faced painted steel panels, specially designed for radiochemistry laboratories, possess the advantages of a finished type of product and the possibility of more rapid and standardized replacement, with no associated wood to hinder decontamination procedures.

Adequate ceilings can be made from either of these materials.

Wall and Ceiling Coatings

Properties of suitable wall and ceiling coatings include ease of decontamination by washing, chemical resistance, ease of removal and replacement in the event of severe contamination, and cost of application. A more detailed discussion of these items is given later.

For the low-level-activity laboratory, a surface coating that satisfactorily withstands the laboratory atmosphere and periodic washing or scrubbing should be adequate for general use on mild steel panels. Stainless steel needs no protection in such an application.

For areas that are subject to a greater-than-average splash or spillage probability, a strippable film, preferably a vinyl type, may be applied over the basic surface or coating. The customary flat, baked alkyd coating, which can be furnished on mild steel panels, is probably adequate for the basic surface coating. The chemical resistance of this material is not nearly as great as that of some vinyl maintenance coatings, but has been found to be sufficient to withstand the general atmosphere of a well-ventilated laboratory as well as the washings and mild reagents that may be encountered. At the same time, such a finish provides a good base for vinyl strippable films of high chemical resistance.

Sealing Cracks Between Wall Panels

The use of removable panels introduces the problem of sealing the cracks between sections to prevent lodgment of radioactive material. The sealing material should be easily removable, nontacky, resistant to washing, economical to apply and neat in appearance. Taping the cracks with polyethylene or vinyl tapes is rapid, not excessive in cost, and, with care, can be made satisfactory in appearance. A mechanical roller can be used for application. One disadvantage is the sticky line of adhesive at the edges of the tape which in time might capture dirt and radioactivity.

A good technique involves caulking the cracks with a special thickened thiokol caulking compound that sets to a firm rubbery consistency without shrinking. A neat joint can be obtained by temporarily masking each side of the crack with tape and applying the putty with a knife. This procedure produces a uniform narrow seam of light brown caulking that adheres to both panels and is flush with the wall surface. When necessary, a sharp knife can remove most of the material rapidly as a continuous strip. If desired for appearance or resistance to acids, the caulking may be coated with a chemically resistant paint.

Sealing Joints Between Wall and Floor

Because of variations in the crack width caused by inherent nonuniformity in the floor level, this type of joint can be sealed most conveniently with a caulking material, such as the thiokol mentioned above, applied to form a cove. Where the crack is excessively large, a preformed rubber strip and caulking will insure a tight seal.

Decontamination

General clean-up techniques have already been mentioned. However, should it be necessary to remove a baked alkyd or vinyl coating itself, a conventional acetone-benzene-paraffin paint remover can be used to soften the film for careful scraping and the panel can be repainted.

Knowledge of the extent and type of contamination will determine whether clean-up should be attempted in place or whether the panel should be removed to a special decontamination area.

Bench Tops

Bench tops and similar working surfaces are subject to a high probability of contamination. The frequency of the contamination can be reduced by using such removable primary barriers as absorbent paper with impervious backing, plastic sheeting, or large shallow trays of stainless steel or disposable molded plastic. However, the probability of a spill reaching the bench surface is still sufficiently great to warrant special consideration.

Some of the most important requirements for a bench top in a conventional chemical laboratory are that it have minimum porosity, be resistant to attack by common chemical reagents and heat, be rigid and possess moderate impact strength. A bench top for use in radioactivity work should possess these characteristics and, in addition, have a nonflammable surface that is decontaminable by washing or moist-scraping techniques. It is desirable that the top be low in cost and ultimately combustible so that in the event of severe contamination, it can be disposed of by special incineration methods. The bench top should be readily removable for decontamination or disposal and, for this reason, should have no permanent attachments such as services.

A fairly extensive survey of the materials most commonly used in conventional chemical laboratories for bench tops has indicated that most fail to fulfill the requirements satisfactorily.

For radioactivity laboratories, a stainless-steel-plywood laminate is considered to be a satisfactory bench top. The steel surface is resistant to corrosion and may be decontaminated with acid. While the metal would not be easily disposable, the wooden backing could be burned off to reduce the bulk for ultimate disposal, as in the similar case of the wall panels mentioned earlier.

Masonite, of the very hard and dense type known as die-stock, seems particularly well adapted for use as a bench-top material, particularly when coated with a chemically resistant material such as baked furfuryl alcohols. It is low in cost, may be disposed of by incineration, has low moisture absorption and is resistant to physical damage. It can also be decontaminated by appropriate moist-scraping techniques.

Suggestions—For general purposes, a bench top constructed from 4, 8 or 12-foot-long sections of ½-inch-thick masonite die-stock might be used. The top surface and sides should be given at least three baked coats of a high-grade furfuryl or vinyl-resin coating. A drip groove should be milled in the under side of the bench top, just back of the front edge to prevent spills from running back.

If greater rigidity is desired, it is possible to use thicker stock, to use full framing, or to fasten angle irons to the under side of the bench top. Cracks and joints can be caulked with specially thickened thiokol.

The technique of attaching bench

tops to the wall and supporting them with diagonal members running to the base of the wall offers the possibility of an easily cleanable floor under benches. For occasional heavy loads, auxiliary legs can be provided.

An alternate bench top can be made up of a stainless-steel-plywood laminate consisting, for example, of 24-gauge, 18-8 stainless steel, bonded to $\frac{3}{4}$-inch plywood on top and sides. The lower front edge can be so shaped as to provide for drip at that point. While it is very doubtful that a bench top of this construction would be combustible under conditions of normal use, the possibility could be minimized by specifying a phosphate-type, fire-retardant paint on the wooden portions. The cost of such bench tops would be almost double that for the die-stock construction noted above.

Chemically Resistant Paints

In the earlier discussion of walls and ceilings, it was suggested that the baked alkyd paint commonly applied by the manufacturer of steel wall panels would be satisfactory for the walls and ceilings of the low-level laboratory where the chances of spillage are not very great. There remain, however, metal, wood, or concrete surfaces, such as those of laboratory furniture, the outsides of duct work, and wall and floor areas not treated in accordance with previous suggestions, that may also require a coating of some sort.

Usually the simplest coating is paint which, in areas of expected contamination, may itself be covered with a strippable film as discussed later. The paint should be as chemically resistant as possible to prevent adsorption, absorption, or penetration of the active chemicals or their solvents to the basic structural layer under the coating. Good chemical resistance also allows the use of strong decontaminating procedures. Paints capable of being applied relatively free of brush marks are desirable. In addition, floor paints should have good abrasion resistance.

It is difficult to offer specific suggestions for proprietary paints without giving brand names of the manufacturers, and such suggestions are often misleading because formulations are changed from time to time.

Quite a few commercially available paints were tested in the present study for resistance to weak and strong acids (both oxidizing and nonoxidizing), strong alkalies and several representative solvents. It is possible, therefore, to draw a few generalizations as a guide to selecting chemically resistant paints for laboratory coatings. It must be emphasized, however, that each product should be tested under simulated use conditions if the best paint for the purpose is to be found. For example, a floor paint required in areas where spillage is likely to be largely ketonic solvents would be different from that required for areas where aqueous acids or alkalies are used exclusively. In the present discussion, only air-drying paints are considered.

Among those types of paints which were tested, generally good chemical resistance was found among the vinyls, styrenated vinyls, phenolics, tung-oil phenolics, and furfurals.

It was found that not all paints claimed to be one of these types showed good resistance, however, probably because of dilution with other less-resistant materials. Abrasion resistance varied with the brands from poor to good. No useful generalization could be made on this point except, possibly, that those paints specifically designed for floors were longer wearing.

The *vinyls*, in general, show excellent resistance to acids and alkalies. All but one of the commercial vinyl paints tested were softened by ketones, chlorinated and aromatic solvents.

The *styrenated vinyls* are not quite as good in general chemical resistance as the vinyls but show somewhat better leveling out of brush marks.

The *phenolics* are not quite as resistant to strong acids as the vinyls but show better solvent resistance in general. Some of the phenolics can be applied in relatively thick coats and thus provide greater abrasion resistance per coat.

Tung-oil modified phenolics show fair to good acid and alkali resistance, poor solvent resistance, but good leveling out of brush marks.

Furfural paints show fair-to-good acid and alkali and general solvent resistance but are limited in color to black.

In actual practice, one of the better vinyls is working out quite satisfactorily as a floor paint for a radioactivity chemical-engineering area.

Strippable Coatings

As a primary barrier against contamination in areas where spillage is expected, strippable coatings may be very helpful.

Vinyl and polyethylene adhesive tapes (both of which are available commercially in widths of at least 20 inches) have been noted earlier and are suited to covering cracks, utility pipes, hoods, and special areas such as valves, doors, drawer handles, etc., where their ease of application and ability to be stripped off intact are advantageous.

Strippable coatings of the solvent-applied type, as opposed to tapes, are usually vinyl polymers and have chemical resistance similar to that of vinyl paints. They cannot be applied over vinyl paints without introducing a suitable "parting" compound, but they will strip easily from baked alkyd finishes. There is considerable variability among these products, particularly in their ability to form a clear, smooth coating that retains its strippability over a long period of time.

Aqueous vinyl dispersions that can be used as strippable coatings have recently appeared on the market, although they are primarily intended to be easily applied long-wearing floor coatings (see *Continuous Floorings*).

Sink and Drainage System

It is presumed that radioactive materials other than those at an innocuous level of activity will find their way into drainage systems only by accident, but provision should be made, for example, by the use of flanged joints, for easy removal of pipes in case of severe contamination.

Suggestions—For drains and piping, both cast iron and silicon iron should be considered. Silicon iron is more acid resistant, but its higher cost makes the selection a matter of over-all economics. In general, where proper precautions against corrosion are taken (such as providing a generous slope to horizontal runs and insuring proper dilution of acids before disposal), the less expensive cast iron is suitable.

For sinks, weldable stainless steel seems to offer the best decontaminabil-

ity and service featuers. Welds should be smoothed and corners rounded to reduce the trapping of contamination. A 2B mill finish is generally adequate. Design should provide for ease of demounting of all parts, especially traps, with little hazard to workers, in the event of accidental lodgment or gradual build-up of dangerous contamination. The use of an inexpensive plastic sink liner extending down into the drain pipe allows easy removal and disposal in case of contamination.

Hold tanks for the monitoring of waste liquids may be of glass-lined steel or stainless steel, the former being preferred because of greater resistance to hydrochloric acid.

Hoods

The greater part of work with radioactive materials is usually carried out in hoods. This results in more frequent contamination of the exposed interior surfaces of hoods than of any other area in the laboratory. It is, therefore, important that the interior surfaces be smooth with rounded corners and contain no projections to which dust might cling or which might be difficult to decontaminate.

Ideally, it is believed that the hood should be readily removable in one piece to a central decontamination area. However, requirements of different types of work may preclude such a construction in all cases, and where it is not possible, the hood should at least be removable in sections for decontamination.

Suggestions—The preferred material for vertical hood surfaces is stainless steel, of a type that can be readily welded. Where only a few hoods of special design will be constructed, the labor cost will usually outweigh the material cost and stainless steel would not be much more expensive than other materials. Recently, stainless steel hoods designed for radioactivity work have become commercially available at a cost lower than similarly designed units constructed individually.

Stainless-steel-covered plywood, formed and soldered so that no wooden surface is exposed, might effect a saving over the necessarily heavier unsupported stainless steel sheeting where a large number of hoods is involved.

For low-level work, it is probable that baked, alkyd-coated, mild steel panels covered with a vinyl-strip-coat primary barrier, as suggested for some areas of walls, would be satisfactory.

The floor of the hood can have the same character as a bench top, for which suggestions have already been made, but an integral hood floor should be considered, particularly in the case of the all-stainless construction.

Ducts

Primary radioactivity requirements for exhaust ducts from hoods are that they be of minimum length compatible with over-all laboratory design and resistant to materials that will be exhausted from the hoods. They should be removable with a minimum of trouble and danger to maintenance personnel in the event of severe contamination.

It would be desirable especially for perchloric acid hoods to be able to

flush the ducts with water periodically without demounting.

While it would be worthwhile to be able to dispose of contaminated ducts by incineration, we are not familiar with any material which is at the same time sufficiently fire-resistant and otherwise suitable.

Suggestions—Three materials seem satisfactory for use with a few limitations. Ducts fabricated with flanged ends from sheet steel coated by a special process with zinc, asbestos, and asphalt, successively, have provided excellent service in chemical laboratories where organic solvents are not encountered in excess. Cost is approximately 75% greater than for galvanized-iron construction. Installed cost of a flanged, 24-gauge, type 302, stainless-steel duct is comparable to that of the coated steel. It is suitable for almost all service except where appreciable concentrations of hydrochloric acid are concerned. By using the more expensive type 316 stainless steel, resistance to chlorides can be improved considerably.

A recently devised type of duct has some attractive features. The duct consists of alternate layers of asbestos paper and a special, chemically resistant coating that shows excellent resistance to acids, alkalies and many solvents. By virtue of this alternate-layer construction, resistance to both solvents and chemicals is increased. Joints between duct sections are sealed with cement of similar composition as the coating and are reinforced with a neoprene tape and steel strap. This allows for ease of removal in the event of contamination.

* * *

The authors are indebted to manufacturers and users of the materials discussed here, as well as to many workers in the field of radioactivity for the information and services they contributed.

Special acknowledgments are due to Messrs. R. S. Robinson and J. L. Sienczyk of the staff of Arthur D. Little, Inc., who assisted in the study on which this paper is based.

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Have YOU an instrument problem?

The June, 1951, issue of NUCLEONICS will contain a special report on

"Practical Aspects of Radioactivity Instruments"

Sections on Construction, Testing and Servicing, and Calibration will contain up-to-date, usable information that has been compiled by experts in the radioactivity instrumentation field. As indicated by the title, "practical aspects" will be emphasized.

—The Editors

RADIOACTIVE STANDARDS AND UNITS*

The curie was initially defined in 1910 and was meant to apply only to radon. In 1950 the unit was redefined by international agreement and extended to any radionuclide

By F. A. PANETH

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EARLY IN THE HISTORY of radioactivity the need for standards was felt; without them the results obtained in different laboratories could not be compared, and the application of radioactive rays in therapy lacked a reliable foundation.

Under the presidency of E. Rutherford, and with S. Meyer as secretary, an International Radium Standard Commission was constituted; the other members were B. Boltwood, Mme. P. Curie, A. Debierne, A. S. Eve, H. Geitel, O. Hahn, E. v. Schweidler and F. Soddy. In 1912 the Commission decided to acquire a preparation of the purest radium chloride ($RaCl_2$), made for this special purpose by Mme. Curie, and to declare it to be the international standard, to be used exclusively by members of the Commission; it weighed 21.99 mg. At the same time the Vienna Academy of Sciences was asked by the Commission to guard as the second international standard, under the same restricting regulations, one of three radium chloride preparations made by O. Hoenigschmid; the one chosen by the Academy contained 31.17 mg.

It is, of course, very unusual to have more than one international standard of anything. This procedure was, however, justified in the case of radium standards because of the difficulty of the measurements involved. Once prepared, the standards had to be kept in sealed glass tubes; while the weight of the preparations could probably be relied upon to an accuracy of one in a thousand, the gamma-ray measurements which had to be used for all comparisons could not be guaranteed to better than about 0.3%. Within this accuracy, the two international standards showed no difference when compared in Paris in 1912 by members of the Commission; but the actual agreement was most likely better than could at that time be proved by gamma-ray measurements.

If an unknown quantity of a more or less chemically pure radium salt had to be measured with the highest possible precision—for example, for the calibration of one of the "national" radium standards—the most reliable line of conduct was to carry out these gamma-ray measurements quite independently, and with somewhat different instruments, at the Laboratoire Curie in Paris and at the Radium Institute in Vienna, using their respective international standards. Each of the official certificates of the national standards bears witness to this procedure; the final figure given therein is the mean of the two calibrations. It was customary to call "primary" radium standards those defined by precision weighing of a quantity of purest radium salt, and "sec-

* This paper is reprinted with the permission of the author and the editors of *Nature*, in which it originally appeared [Vol. **166**, 931 (1950)].

ondary" standards those measured by γ-ray comparison with a primary standard. The radium contents of both were expressed in grams of radium element.

Radon Standardization

Another unit had to be introduced for the standardization of radon—a radioelement of at least equal importance for medical use—since it was impossible to weigh or, for that matter, to measure volumetrically such minute quantities of gas with any accuracy. The gamma-ray comparison of radium salts was, strictly speaking, always a measurement of the gamma rays of RaC, after radon and the active deposit had reached equilibrium with the radium; it was therefore quite natural to express radon quantities by the weight of the radium with which they were in radioactive equilibrium.

At the International Radiological Congress at Brussels in 1910 one "curie" of radon was defined as the quantity of radon in equilibrium with one gram of radium (element). Soon it became customary to speak also of curies of RaC, etc.; it meant always the quantity in equilibrium with one gram of radium.

In 1930 the International Radium Standard Commission recommended officially that the use of the term "curie" be extended to include the equilibrium quantity of any decay product of radium; but the Commission did not favor its extension to radioelements outside the radium family. On the other hand, it stated that the unit quantity of any radioactive element might be expressed in terms of the mass which is equivalent to one gram of radium, either with respect to the effect of the rays, or to the number of atoms decaying per second. The first procedure was, for example, used in specifying quantities of mesothorium by the weight of radium giving an equivalent intensity of gamma rays; in the latter sense, one could define 1 gm of radium-equivalent as that quantity of any radioactive element for which the number of atoms decaying per second was the same as that in 1 gm of radium. It was recommended by the Commission that one should provisionally use as this number the value 3.7×10^{10} disintegrations per second; but this figure was not known with an accuracy of less than 0.5% and did not form part of any definition.

Since those days, two important developments have taken place: the production of artificial radioelements of great practical importance, and the construction of apparatus which makes counting of emitted particles a routine operation. The strength of a source of, let us say, radioactive phosphorus or iodine could conveniently be expressed by the number of emitted particles, but it was usually preferred to give the result in curies, using 3.7×10^{10} as conversion factor.

This habit was not satisfactory in view of the fact that the curie was strictly defined only by the weight of a radium salt, and that its disintegration rate was still open to discussion. The situation was aggravated in 1947 by a new determination of the number of atoms disintegrating per second in one gram of radium, claimed to be considerably more accurate than the previous ones; it reduced the figure to 3.6×10^{10}. The acceptance of this new value was recommended in July, 1948, at a meeting in Amsterdam of the International Union of Physics;* but the authority which would have had to sanction this recommendation, the International Radium Standard Commission, had practically ceased to function, in spite of the devotion of Prof. Stefan Meyer in Vienna, who had been elected president of the Commission after Lord Rutherford's death in 1937, and who, up to his own death in 1949, remained

* *Nature* **164**, 263 (1949).

deeply interested in all questions of radioactive standardization.

The Curie Redefined

Following an informal discussion of chemists and physicists in London in July 1947,* the International Council of Scientific Unions in 1948 asked the International Union of Pure and Applied Chemistry and the International Union of Pure and Applied Physics to nominate six representatives each to a new Joint Commission on Standards, Units and Constants of Radioactivity; the Union of Chemistry was to be considered as the mother union of this Commission. The first meeting of the Joint Commission took place on September 8, 1949, in Amsterdam, the second on July 17, 1950, in Unesco House in Paris. At this last meeting, after some discussion, unanimous agreement was reached on the following new definition of the curie:

> *The curie is a unit of radioactivity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is* 3.700×10^{10}.

It is to be noted that this new definition completely severs the former special connection of the curie with radon and radium. The value 3.700×10^{10} disintegrations was chosen because it was the intention of the Commission to keep the new curie as near as possible to the old value of this unit. It was not felt that the measurement leading to the figure 3.6×10^{10} was sufficiently more convincing than the older determinations which had been the basis of the generally accepted value of 3.7×10^{10} disintegrations; nor did it seem necessary, or advisable, to introduce a further unit based on 10^6 disintegrations per second; before the constitution of the Joint Commission of the International Council of Scientific Unions, such a unit had been advocated under the name of a "rutherford."†

It must be kept in mind that the fundamental radium standards in Paris and Vienna are defined by the weight of radium, and cannot now be expressed accurately in curies (in the new sense of this term). These primary radium standards, and the secondary standards derived from them, are still indispensable if one has to measure radioactive substances which cannot be "counted" but only compared by their gamma rays; they will have to be employed, for example, for the measurement of the many radon preparations in medical use. Theoretically, the strength of such a source should now be given only in terms of its equilibrium quantity of radium in grams; but for all practical purposes it will still be permissible to equate 1 gm of radium with 1 curie, until new determinations show that the chosen figure 3.700×10^{10} does not correspond with sufficient accuracy to the number of alpha particles emitted per second; it will then be easy to use a small correction factor. Experiments to determine with high precision the "curie value" of 1 gm of radium, that is, the number of atoms disintegrating per second, are under way. The figure for the half-life of radium and other important constants of radioactivity depend on it.

Other Commission Decisions

The position with respect to the two international radium standards is as follows. Since it is not safe to keep a radium salt of some strength sealed up in a glass tube for an indefinite time, because of the accumulation of gas which may exert after a while a dangerous pressure, both original international standards were replaced, in 1934, by new standards prepared by Hoenigschmid in connection with his second, and still more accurate, series of atomic weight determinations of radium. The

* *Nature* **160,** 778 (1947).
† *Science* **103,** 712 (1946) and *Phys. Rev.* **77,** 142 (1950).

new standard in Paris contains 22.23 mg radium chloride and the new standard of the Austrian Academy of Sciences 30.75 mg. The former used to belong to the International Radium Standard Commission, but, with the consent of all the surviving members of this Commission, has now been transferred into the ownership of the new Joint Commission on Standards, Units and Constants of Radioactivity. It will remain under the care of the Bureau International des Poids et des Mesures at Sèvres, but may be kept in the Laboratoire Curie in Paris; the Vienna standard is permanently housed in the Institute for Radium Research.

The Joint Commission discussed the possibility of making use of artificial radioactive isotopes for secondary gamma-ray standards, and recommended that samples of cobalt-60 should be prepared by several laboratories and exchanged for comparison; but the time does not seem ripe for using this nuclide as a radioactive standard at the international level, since its half-life is not yet known with sufficient accuracy. For beta-ray standards RaE (in equilibrium with RaD), strontium-90 and thallium-204 seem promising, but here again it was the opinion of the Commission that it would be premature to make an international decision. Attempts to prepare such standards for distribution were encouraged since they would be very valuable for the calibration of counting equipment in absolute units.

Among other topics discussed at the Paris meeting of the Joint Commission was the adoption of the term "barn" for 10^{-24} cm^2 as a unit of cross section for nuclear processes; the Royal Society had asked the Commission to give its opinion on this question. It was felt that there is not any new unit involved which would demand an international definition, but that the expression "barn" in the above sense should be accepted since it is in common usage in the United States.

Of the surviving members of the last International Radium Standard Commission, Sir James Chadwick, O. Hahn, S. C. Lind and A. Piccard have joined the new Commission as advisory councillors; and, to replace S. Meyer, the present director of the Vienna Radium Institute, Prof. Berta Karlik, has also been invited to become an advisory councillor. It is hoped in this way to secure for the deliberation of the Joint Commission the assistance of these experts, if required. The members of the Joint Commission on Standards, Units and Constants of Radioactivity are: as delegates of the International Union of Chemistry, Miss E. Gleditsch (Norway), G. Hevesy (Sweden), W. C. Johnson (United States), F. Joliot-Curie (France), F. A. Paneth (Great Britain, *president*); G. T. Seaborg (United States); and as delegates of the International Union of Physics, Sir John Cockroft (Great Britain), L. E. Curtiss and R. D. Evans (United States), J. C. Jacobsen (Denmark), Mme. Joliot-Curie (France) and C. J. Sizoo (Netherlands, *secretary*).

CORRECTION . . .

In the chart on pages 56–57 of the April issue ("Nomogram for Calculating Shielding for Co^{60}" by G. A. Bennett) the legend for the shielding thickness scale marked D_2 was omitted. Reading from left to right, these scales should be labeled:

lead; iron; concrete or aluminum; and water.

RADIOLOGICAL HEALTH*

Health officers have a public relations job to do where the radiological health of community and industry is concerned. Here are suggestions on how they can get started

By EDWIN G. WILLIAMS

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THE TIME has come for the public health authority to become acquainted with the problems of radiological health.

Because the scientist who works with radioactive substances will so often ignore personal hazards to achieve experimental results, he is not a logical candidate to establish permissible dose values and the safety codes associated with them. This was demonstrated time and again in early experiences with radiation injury among radiologists and other workers. It is the responsibility of the public health authority, then, to work with such groups and urge continued consideration of radiation safety standards.

If we accept the statement that the immediate effects in tissue of all ionizing radiations are harmful, the only tenable philosophy is "Avoid all avoidable ionizing radiation." Any amount of radiation can be worked with safely if proper precautions are taken. No amount of radiation can be worked with safely if proper precautions are not taken.

Maximum permissible doses are not licenses but ceilings. They must be reasonable or they cannot be enforced. In light of our present knowledge, the maximum permissible doses now in effect seem reasonable.

It has been shown that it is feasible to keep actual exposures down to a small fraction of the maximum permissible level. And since our goal is to hold radiation exposure as close to natural background as possible, the standards should be enforced not on the basis of measurable excesses or demonstrable harm, but rather on *principle*. Differentiation between hazardous and nonharzardous conditions must often be arbitrary. If we must err, the error should be on the side of safety.

Our knowledge about the public health aspects of high-energy radiation is developing so rapidly that detailed laws passed at this time might prove inoperable or soon seem foolishly naive. It would seem wiser, then, to write necessary legislation in terms of responsibilities and powers and to rely on expert technical advice, statements of guiding principles, and readily changeable codes for detailed operations.

Planning for a Program

In planning a radiological health program, the public health authority must bear in mind these facts:

1. Man will continue to develop atomic energy.
2. Generally speaking, the public has not been exposed to radiation hazards.
3. We cannot afford the luxury of widespread contamination or

* Based on lecture material for the Inservice Training Course on "Radiological Health" conducted by the School of Public Health of the University of Michigan, Feb. 5–8, 1951.

THE FIVE STEPS . . .

. . . that health departments can take immediately to broaden their interests in radiological health are:

1. Have each health officer who has not done so acquaint himself with radiological health at least on a conceptual basis.
2. Have health officers provided with assistants who possess some degree of technical proficiency in radiological health or can be so trained.
3. Encourage industry, the larger laboratories, hospitals, etc., to employ specially trained people for health physics and radiological health work. (Several universities and the Atomic Energy Commission offer such training.)
4. Start with a modest program of training to include, for instance, monitoring of X-ray and radium operations.
5. Develop programs around specific needs.

radiation injury as a stimulus to bestir ourselves to activity.

4. Sufficient knowledge is at hand to permit development of a radiological health program more adequate for safe living than was true in the beginnning of other, if not most, public health endeavors.

What then is the specific challenge here to each health department? No standard pattern can be applied. Some communities will be primarily concerned with the public health aspects of medical and dental uses of radiation, some with radioactive wastes from large laboratories or plants, some with the industrial environment of the worker.

In any case, a community-wide program to acquaint the public with the health aspects of radiation so that they can develop a true perspective and respect for, rather than fear of, radiation is certainly, in part at least, the responsibility of the health department. Other steps, more immediate in nature, that can be taken are shown above.

The radiological health activity in any one community at first will not be large and most probably will be placed in the organizational or professional category showing the keenest interest or having what at the moment seems to be the primary responsibility. Great care must be exercised to insure that this specific assignment carries with it no implication that other parts of the health department or other departments dealing with health matters are without radiological health problems or are relieved of responsibilities concerning them.

Sooner or later thought will have to be given to the question of whether it is better to have each category carry on its own radiological health program or have the activity as an entity operate an over-all program and render services in the other specific categories. There are good arguments for either decision and in many locations a combination of the systems will be advantageous.

Protective measures, monitoring methods and instrumentation will vary with the installation or procedure under consideration. Each unit dealing with radiation must assume responsibility for the protection of its staff and of all other people who may be or may become exposed as a result of the activities of the unit.

It is the responsibility of the public health worker to provide advice and guidance in these matters and to assure himself and the public that good practices are constantly in force. —END

Quantitation of Alpha Emitters in Bone*

Amounts of radon lost by diffusion from bone sections containing radium are found by counting total number rather than length of tracks in autoradiographs. The method seems adaptable to finding amounts of other alpha emitters in bone

By BRUCE L. MILLER and FRANK E. HOECKER

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AUTORADIOGRAPHIC STUDIES of the distribution of alpha-emitting substances in bone and other tissues have recently been made. These survey studies yield much useful information regarding relative concentrations in different tissues and in different portions of the same tissue. But it is desirable to make quantitative determinations of the amount of radioactive substances associated with a given alpha-particle concentration pattern. This is especially true in studies of radium that has been deposited metabolically in bone.

Recent autoradiographic studies of radium distribution in the bones of human victims of radioactively induced bone sarcomas have revealed the presence of unexplained concentrations of radium in certain regions (*1*). The desirability of quantitative evaluation of the amount of radium in these regions and of the associated alpha-particle tissue dose is at once apparent.

The problem of the precise evaluation of the amount of radium associated with the alpha-particle tracks recorded in a nuclear emulsion exposed in contact with a bone section containing radium is especially difficult because of the production of radon as one of the disintegration products. No precise quantitation is possible without a knowledge of the amount of radon lost by diffusion from the bone. This may be most conveniently expressed as the Ra/Rn activity ratio. The fractional amount of Rn lost from the living human body is known with reasonably good accuracy (at least after the radium has been in the body sufficiently long to be considered as "fixed") (*2*). But the diffusion from old, dried bones may be quite different, particularly after they have been cut into sections 30 or 40μ thick for microscopic and autoradiographic study.

Quantitation of radium in bone is particularly difficult because of the small amount present. In studies of human bones, the amounts are so small that autoradiographic exposures of about 400 hours are required to produce enough tracks for counting purposes (*3*). Obviously, instrumental counting is not feasible and quantitation must be based on alpha-track counts.

Track counting also appears to be the only practicable method for evaluating the Ra/Rn activity ratio. However, attempts to evaluate this ratio by measuring track lengths in the autoradiographs appear to have been unsuccessful because of uncertainties that have been introduced by emulsion shrinkage and distortion (*4*).

* This work has been sponsored jointly by the Office of Naval Research under Contract N6 onr 260 T.O.I. and by the U. S. Atomic Energy Commission under Contract AT(11-1)-83.

The purpose of this paper is to describe a method by which the Ra/Rn activity ratio may be evaluated by an autoradiographic procedure which depends only on the number of tracks counted and does not involve the measurement of track lengths. The method promises to be a reasonably reliable one for quantitatively identifying naturally radioactive substances that have been deposited in bone tissue.

Although the results of the experiment are based on a limited amount of data, improvements are being made; and more data will be taken. Considerable improvement in the precision of the result is needed. However, since no other data is available this result serves as a first valid approximation for calculations of the quantity of radium associated with a given alpha-track density and of the associated alpha-particle tissue dose.

Experimental Method

Consider a volume of bone tissue in which is fixed a quantity of Ra in radioactive equilibrium with its disintegration products. A direct manner of determining the ratio from a plate that has been exposed to this region of bone tissue would be to count the Ra alpha tracks exclusively and then to count the tracks produced in the same time by Rn alphas only. A ratio of these two counts would yield the fractional amount of Rn remaining in the locality of the deposited Ra. This oversimplification of the problem describes the basis of the method.

Since alphas from Ra have a shorter range than those of its disintegration products, the tracks due to Ra alphas can be eliminated from an autoradiograph by filtration. The remaining tracks will be due to alphas from Rn RaA, RaC′ and RaF. It will be assumed that Rn, RaA, and RaC′ each contribute one third of the tracks left after the Ra alphas have been filtered out. Because of the long half-life of RaD (22 years), the alpha activity due to RaF will be negligible in the bone specimens referred to in this paper.

The experimental procedure is first to make a count of the alpha tracks in an autoradiograph in which all of the alpha emitters are represented and then, after the Ra alphas are filtered out, to make a second exposure to get a count of only those tracks that depend on the amount of Rn remaining.

To make use of several simplifying approximations in the mathematical treatment of this problem, it is desirable that the portion of the bone section used as the radioactive source is small compared to its distance from the plate. If the exposure time of these plates is to be of a practical duration, a large concentration of Ra in the bone is necessary.

The rat used in this work was given a series of injections of Ra solution amounting to an unusually large total dosage of 190 μg of Ra. This animal was sacrificed the eighth day after the last injection and it was estimated that 60 μg of Ra remained, most of it within the bone tissue. Cross sections were cut from the femur in the epiphyseal region, where experience had shown that the radioactive concentrations were the largest. These sections, cut for mounting in the exposure units, were about one millimeter thick and several square millimeters in area.

Figure 1 shows the details of a slide unit on which a bone section is mounted during exposure. The bone section is held in place by a phosphor-bronze leaf spring. An area of the bone section, about 1.5 mm in diameter, is exposed to the plate through the circular aperture, the hole of which is countersunk as deep as possible to prevent the walls from filtering out alphas emitted at oblique angles from the exposed portion of the bone. An adjustment screw serves as a stop for positioning

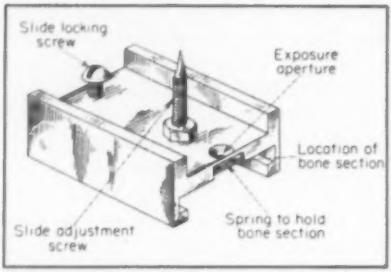

FIG. 1. Slide unit for holding bone section

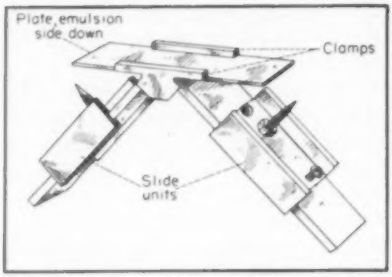

FIG. 2. Exposure unit showing photographic plate and slide units

the slide correctly on the exposure unit. The proper length of the adjustment screw is determined by the angle between the slide unit and the plate, the distance from the center of the aperture to the base of the adjustment screw, and the desired distance of separation between the bone section and the plate. The locking screw maintains the slide unit at the proper position on the exposure unit.

The entire exposure unit, containing the nuclear track plate and the two slide units, is shown in Fig. 2. Clamps hold the plate rigid, with emulsion side down. During actual exposure the slide units are positioned farther up the inclined ways to the point where the tip of the screw just contacts the emulsion. This point of contact produces a latent point image on the longitudinal axis of the plate and later serves as a reference point from which the counting region can be located. A safe light must be used during mounting of the plate on the exposure unit.

Filtration was accomplished by placing aluminum foil over the aperture. Since the range of alpha particles is shorter in aluminum than in air, use of an aluminum filter permits the plate to be brought closer to the source. A given area of the plate then subtends a larger angle at the source and intercepts a greater fraction of the emitted alphas. In this way, a given track density can be achieved with a much shorter time of exposure.

Theoretical Basis

To derive any information from the track counts made from the plate, the relationship between the count made within a given region on the plate and the concentration of the contributing radioactive elements in the bone must be known. To find this relationship, it is sufficient to consider only one alpha-emitting element in the bone. The resulting expression can be readily generalized for the case of several different alpha emitters. It is to be assumed that this radioactive element is distributed uniformly throughout the bone section.

Figure 3 shows a schematic arrangement of the filtered source and the plate. Because the distribution of tracks is almost radially symmetric for a small range of ϕ, counting is done along an arc of constant radius. The bone section is oriented at the angle θ_0. Its position is such that the alpha particles whose tracks are counted are emitted in directions almost normal to the cross-sectional surface of the bone. These particles are therefore representative of a radioactive source of maximum depth; this yields, then, for given values of r and h, the largest possible flux of alphas through the area dA.

Since the stopping power of bone tis-

sue for alphas is large relative to that of air, the effect of self-absorption of the source must be considered. In the portion of the plate where $\phi \sim 0°$ and $\theta \sim \theta_0$, the region of the exposed area of the bone section that contributes the alphas to the area dA is very nearly a plano-convex lenticular volume. This region can be approximated by a cylindrical source of alpha particles having a cross-sectional area equal to that of the exposed area of the bone and a height τ_i. This τ_i is the depth of the true volume of the alpha particle source measured along the axis of the circular area. The error introduced by this approximation is less than the volume difference between a cylinder and a cone having the same heights and radii as the spherical segment of the lenticular volume. This volume difference, compared with the substituted cylindrical volume, is always small, thereby making the approximation valid. Thus the number of alpha particles emitted per second from a cylindrical volume element of area S and thickness $d\tau$ is given by

$$dN_i/dt = \rho_i \lambda_i S\, d\tau = \Gamma_i\, d\tau \qquad (1)$$

where ρ_i = the number of atoms per cm³ which may emit alpha particles of range R_i in air, and λ_i = the decay constant of the radioactive element.

Now τ_i is a function of the θ and ϕ coordinates of dA. Just how strong a dependence this is can be shown by a straightforward though somewhat lengthy geometrical argument, the result of which is:

$$P_b\tau_i + P_{Al_i}\zeta_0 = (P_b\tau_{0_i} + P_{Al_i}\zeta_0)\left(1 - 2\sin^2\theta \sin^2\frac{\phi}{2}\right) \qquad (2)$$

where τ_{0_i} denotes the maximum depth of the bone source (occurring when $\phi = 0°$); ζ_0 is the thickness of the aluminum filter; and P_b and P_{Al_i} are the relative stopping powers of bone and aluminum respectively. The relative

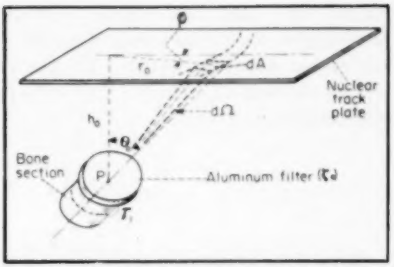

FIG. 3. Relative positions of bone and plate as used in experimental procedure

stopping power is the distance in air that has the same stopping power for an alpha particle of a given energy as has a unit thickness of the absorbing medium. The relative stopping power of aluminum as a function of energy is known (*5*). It is slightly different for each alpha emitter since alpha particles of different energy types are incident on the filter with different average energies. The same would be true for a bone medium; but since the functional dependence is not known, P_b is assumed to be constant for all energy type alpha particles.

The probability that a particle will be incident on dA is equivalent to the probability that the particle is emitted in the solid angle $d\Omega$.

$$\text{Probability} = \frac{d\Omega}{4\pi} = \frac{\sin\theta\, d\theta\, d\phi}{4\pi} \qquad (3)$$

The total number of alpha particles falling on dA per second, dn_i/dt, is the product of the probability that an alpha particle strikes this area and the total number of alpha particles emitted per second. Thus

$$\frac{dn_i}{dt} = \frac{d\Omega}{4\pi}\frac{dN_i}{dt} = \frac{\sin\theta\, d\theta\, d\phi}{4\pi}\Gamma_i\, d\tau$$

or, integrating over t

$$n_i = \frac{t\Gamma_i}{4\pi}\int_{\theta_0-\frac{\delta\theta}{2}}^{\theta_0+\frac{\delta\theta}{2}} \sin\theta\, d\theta \int_{-\phi_0}^{\phi_0} d\phi \int_0^{\tau_i} d\tau \qquad (4)$$

Since the counting region extends throughout the same small range of ϕ on either side of $\phi = 0°$, it can be shown numerically that τ_i very closely approximates τ_{0i} and

$$n_i = \frac{t\Gamma_i}{2\pi}\phi_0 \int_{\theta_0-\frac{\delta\theta}{2}}^{\theta_0+\frac{\delta\theta}{2}} \tau_{\theta_i} \sin\theta \, d\theta \quad (5)$$

Now τ_{θ_i} is dependent on θ. The energy of an alpha particle coming from a depth τ_{0i} of bone is expended in the bone, in the filter (if present), and in the air intervening between the plate and the bone section. Therefore

$$R_i = P_b\tau_{0i} + P_{Al_2}\zeta_0 + \chi[\sigma(\theta) - \zeta_0] + K \quad (6)$$

R_i = range in air of alpha particles from the ith successive alpha emitter of the series (assuming Ra to be the first) if the pressure is 760 mm of Hg and the temperature is 15° C.

$\sigma(\theta)$ = air distance from the bone section to the plate, measured along the axis of the bone section.

χ = factor for conversion of the actual air distance under room conditions to its equivalent range for a temperature of 15° C and pressure of 760 mm of Hg.

K = the range in air equivalent to a 3-μ distance in the emulsion. Inserting K in Eq. 6 means that images less than 3μ in length could not be discerned as tracks.

Since $\sigma - \zeta_0 \sim \sigma$, the solution of Eq. 6 for τ_{0i} is:

$$\tau_{\theta_i} = \frac{R_i - P_{Al_2}\zeta_0 - \chi\sigma(\theta) - K}{P_b} \quad (7)$$

Substitution in Eq. 5 gives:

$$n_i = \frac{t\Gamma_i\phi_0}{2\pi P_b}\left[(R_i - P_{Al_2}\zeta_0 - K)\int_{\theta_0-\frac{\delta\theta}{2}}^{\theta_0+\frac{\delta\theta}{2}} \sin\theta \, d\theta - \chi\int_{\theta_0-\frac{\delta\theta}{2}}^{\theta_0+\frac{\delta\theta}{2}} \sigma(\theta)\sin\theta \, d\theta\right] \quad (8)$$

Though these integrations are not complex, the substitution of the limits makes a rather cumbersome expression with which to work. A simpler expression can be obtained by a change in variable and a further approximation. Now $\sin\theta \, d\theta = d(-\cos\theta)$ and $d(-h_0/\sigma) = (h_0/\sigma^2)\, d\sigma$ and, substituting $\cos\theta = h_0/\sigma$, the first term within the brackets of Eq. 8 becomes:

$$(R_i - P_{Al_2}\zeta_0 - K)\int_{\sigma_0-\frac{\delta\sigma}{2}}^{\sigma_0+\frac{\delta\sigma}{2}} h_0/\sigma^2 \, d\sigma$$

Integrating; expressing σ in terms of h_0, r_0, and γ, where 2γ is the width of the ring in which the tracks are counted; and then expanding the result in a binomial series; yields, on neglecting second and higher order terms:

$$\frac{R_i - P_{Al_2}\zeta_0 - K}{\sigma_0} h_0 \frac{2r_0\gamma}{\sigma_0^2} \quad (8a)$$

The second term of Eq. 8 becomes:

$$-\chi\int_{\sigma_0-\frac{\delta\sigma}{2}}^{\sigma_0+\frac{\delta\sigma}{2}} \sigma h_0/\sigma^2 \, d\sigma$$

Again integrating and replacing σ by its expression in h_0, r_0, and γ gives:

$$\frac{\chi h_0}{2}\ln\left(\frac{1 - \frac{2r_0\gamma}{\sigma_0^2}}{1 + \frac{2r_0\gamma}{\sigma_0^2}}\right)$$

When this is expanded in series, the result, after neglecting all terms above first order, is:

$$-\frac{2\chi h_0 r_0\gamma}{\sigma_0^2} \quad (8b)$$

Substitution of Eqs. 8a and 8b into Eq. 8 gives as a result the following

simplification of the expression for n_i

$$n_i = \frac{t\Gamma_i h_0 r_0 \gamma \phi_0}{\pi P_b \sigma_0^3} (R_i - P_{Al_i}\zeta_0 - \chi\sigma_0 - K) \quad (9)$$

This expression relates the concentration of the alpha emitter to the number of tracks produced during a period of time t in a portion of a ring of radius r_0, length $2r_0\phi_0$, and width 2γ.

If alpha emitters of several different energy types are present in the source, the general expression can be written in the following form

$$\sum_i n_i = \frac{th_0 r_0 \gamma \phi_0}{\pi P_b \sigma_0^3} \sum_i \Gamma_i (R_i - P_{Al_i}\zeta_0 - \chi\sigma_0 - K) \quad (9a)$$

Experimental Procedure

The exposures were made in the manner described earlier. The statistical error arising from the random nature of the radioactive decay must be kept small (~3%). To do this, a count of about 1,100 tracks was required. To prevent inconveniently long exposure times and to keep the counting region small to minimize errors of approximation, the total noted was comprised of counts taken from six simultaneous exposures of six different bone sections.

The first series of exposures, requiring about 24 hours, was made without any selective filtering of the four different energy type alpha particles. For the second series of exposures, an aluminum filter was interposed between the bone section and the plate. Its thickness was chosen to eliminate the tracks of Ra and Rn alpha particles from the counting region. This necessitated an exposure of one week.

It is to be understood that in the count of both series of autoradiographs counting regions of the same locality and same extent were involved; that is, the values of h_0, r_0, ϕ_0, and γ were the same in both countings. From Eq. 9a, the appropriate expressions for the total number of counts derived from the first and second exposure series, respectively, are:

$$\sum_{i=1}^{4} n_i = \frac{t_1 h_0 r_0 \gamma \phi_0}{\pi P_b \sigma_0^3} \sum_{i=1}^{4} \Gamma_i C_i \quad (10a)$$

$$\sum_{i=3}^{4} n_i = \frac{t_2 h_0 r_0 \gamma \phi_0}{\pi P_b \sigma_0^3} \sum_{i=3}^{4} \Gamma_i C_i' \quad (10b)$$

where $C_i = R_i - \chi\sigma_0 - K$ and $C_i' = R_i - P_{Al_i}\zeta_0 - \chi\sigma_0 - K$.

Let ν represent the fractional amount of Rn that does not diffuse out of the exposed portion of the bone section after a diffusive equilibrium has been established. The concentration of Rn remaining is proportional to the activity per unit volume. If none of the Rn escapes, and there is radioactive equilibrium between Ra and Rn, the activity per unit volume of the Rn will be the same as that of the Ra. Therefore

$$\nu = \frac{\rho_2}{\rho_2'} = \frac{\lambda_2\rho_2}{\lambda_2\rho_2'} = \frac{\lambda_2\rho_2}{\lambda_1\rho_1}$$

where ρ_2' is the concentration of Rn if there is no loss by diffusion. Then, from Eq. 1,

$$\nu = \frac{\lambda_2 \frac{\Gamma_2}{\lambda_2 S}}{\lambda_1 \frac{\Gamma_1}{\lambda_1 S}} = \frac{\Gamma_2}{\Gamma_1}$$

and $\Gamma_2 = \nu\Gamma_1$.

The quantity Γ_2 is proportional to $\lambda_2\rho_2$, the activity per unit volume. When there is radioactive equilibrium between Rn and its daughter elements, the activity per unit volume of RaA and RaC′ is equal to that of Rn. Therefore $\Gamma_2 = \Gamma_3 = \Gamma_4 = \nu\Gamma_1$.

Equations 10a and 10b then become:

$$\sum_{i=1}^{4} n_i = \frac{t_1 h_0 r_0 \gamma \phi_0}{\pi P_b \sigma_0^3} \Gamma_1[C_1 + \nu(C_2 + C_3 + C_4)]$$

and $$\sum_{i=3}^{4} n_i = \frac{t_2 h_0 r_0 \gamma \phi_0}{\pi P_b \sigma_0^3} \Gamma_3\nu(C_3' + C_4')$$

TABLE 1

Results of Counting Alpha Particles from Bone Sections

Bone section		First series Counts	First series Time	Second series Counts	Second series Time
1	a	144	24 hr 5 min	150	1 wk 5 min
	b	225		240	
2	a	180	24 hr 6 min	198	1 wk 1 min
	b	159		172	
3	a	199	24 hr 5 min	260	1 wk 2 min
	b	269		309	
		total 1,176	*avg* 24 hr 5 min	*total* 1,329	*avg* 1 wk 3 min

from which the following expression for ν is found:

$$\nu = \frac{C_1}{(C_2'+C_4')\,\dfrac{t_2\sum_{i=1}^{4} n_i}{t_1\sum_{i=3}^{4} n_i} - (C_2+C_3+C_4)} \tag{11}$$

This expression does not depend upon the relative stopping power of bone.

All track patterns were analyzed under a microscope with an oil-immersion objective giving an over-all magnification of about 800 diameters. A camera lucida was used for counting. The area it projected into the field of view was a circle about 15 cm in diameter, ruled into five equally spaced vertical segments to facilitate counting. The area outlined on a piece of paper was illuminated from beneath by a light whose intensity could be adjusted to give the proper balance with the illumination of the microscope field. In terms of the field dimensions, this area represented a circle with a 100-μ diameter, which now will be referred to as the "unit counting area."

A track density of more than 40 within this unit counting area is too heavy to permit accurate counting. Therefore, the counts from several such unit areas had to be obtained. Equation 9 involves a count taken from a portion of a ring whose center lies on the plate directly above the bone section. To make an alpha-track count of the area described by this equation requires an adjustment of the microscope stage micrometer so that successive or adjacent unit counting areas along the inner arc of the ring could be viewed.*

An arc of radius $r_0 - \gamma$ was scribed with a pair of dividers on a 3 × ⅞-in. plastic cover slip. This cover slip was taped to the developed plate with the scribed surface toward the emulsion. The plate was manipulated so that within the field of the microscope the successively observed unit counting areas were tangent to the outside of the scribed arc and to each other. The total count for any one bone section was composed of all of the tracks of alphas that were incident within these unit circular areas.

The reference points on each end of the developed plate served as guides to the proper location of the scribed arcs on the cover slip. Two other such points were marked in the same relative posi-

* The area which was actually counted by means of the unit counting areas differed slightly from that involved in Eq. 9. However, in all countings of each exposure series, the same number of unit circular areas were counted. Since the expression for ν, Eq. 11, concerns only the ratio of the counts, this discrepancy introduced no error.

tion on the cover slip. The arc centers were located on the line joining them. The cover slip was positioned relative to the plate so that the two sets of reference points coincided. The arcs were then located correctly relative to the track patterns from each of the two bone sections associated with each exposure unit.

Data and Results

The value of θ_0 was chosen as 45°. This seemed to be an optimum value; decreasing θ_0 rendered a smaller fraction of the track length visible within one focal setting of the microscope, and increasing θ_0 meant a decrease of the track density within the counting region for a given exposure time. The values of h_0 and r_0 were then set at 5.0 mm, making $\sigma_0 = 7.1$ mm. The value of ϕ_0 was the angle whose arc length, at a radius of r_0, was equal to 10 diameters of the unit counting area. (Ten unit counting areas of diameter 2γ were used on each side of the longitudinal axis, $\phi = 0°$.) Since $\gamma = 50\mu$, $\phi_0 = 0.2$ radians.

Table 1 gives the following results

$$\sum_{i=1}^{4} n_i = 1{,}176 \text{ counts} \qquad t_1 = 8.67 \times 10^4 \text{ sec}$$

$$\sum_{i=3}^{4} n_i = 1{,}329 \text{ counts} \qquad t_2 = 6.05 \times 10^5 \text{ sec}$$

The C_i's are evaluated from the alpha particle range values given by Seaborg and Perlman (*6*), and from the following numerical constants under the average conditions of a pressure of 735 mm of Hg and a temperature of 20° C:

$P_{Al_3} = 1.77 \times 10^{3}$* $\quad \sigma_0 = 7.1$ mm
$P_{Al_4} = 1.82 \times 10^{3}$* $\quad \chi = 0.952$
$\zeta_0 = 17.9\mu \quad K = 3\mu \times 1{,}800 \cong 0.50$ cm

* These values were determined from reference *5*.

TABLE 2
Errors Caused by Approximations

Approximation	*Error* $\sum_{i=1}^{4} n_i$	*Error* $\sum_{i=3}^{4} n_i$
Volume of source bone	+0.5%	+1.6%
Substitution of r_{0i} for r_i	+0.7%	+2.3%
Numerical approximation of integrals	−1.0%	−1.4%

Substituting these data into Eq. 11 gives $\nu = 0.40$ as the fractional amount of Rn remaining. This means that the net loss of Rn from the exposed part of the bone section is 60%. The term "net" is used to imply the possibility that Rn diffuses into the exposed portion of the bone from the surrounding masked region.

Errors

The statistical error originating in the random nature of the radioactive decay events is

$$\pm 2.0\% \text{ in } \sum_{i=1}^{4} n_i$$

$$\pm 1.8\% \text{ in } \sum_{i=3}^{4} n_i$$

resulting in a probable error of

$$\pm 2.7\% \text{ in } \sum_{i=1}^{4} n_i \Big/ \sum_{i=3}^{4} n_i$$

The human error entering into the counting is very probably a systematic error of omission; therefore this error will very nearly cancel in the ratio of the total numbers of counts, and can be ignored. The relative probable error in ν, as introduced through the actual counting of the tracks, is ±2.4%.

The errors resulting from the approximations used can be interpreted as

maximum errors in n_i, or in particular in the terms

$$\sum_{i=1}^{4} n_i \quad \text{and} \quad \sum_{i=3}^{4} n_i$$

These are shown in Table 2. These errors combine to produce a maximum error of -2.2% in the ratio of the two terms. The result is an error of $+6.3\%$ in the value of ν.

The errors in experimental procedure, exclusive of track counting, can be represented as errors in the C_i's and C_i''s. The error in σ_0 is a significant term in the expressions for the C_i's and C_i''s. But the involved procedure employed to position the bone section during exposure (and later to select the proper region to be counted) does not afford a substantial basis for its determination.

It is reasonable to believe that the experimental technique has introduced other errors also of unknown magnitude. Some of these errors may be of no consequence, depending upon the nature of the further calculations involving ν. Those that remain can very probably be reduced or eliminated by a redesign of the apparatus.

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" . . . the proportion of declassifiable engineering information published is small indeed compared to that in the fundamental sciences. It is unfortunate, but true, that there has not been the incentive for engineers to write up their work for declassification that exists among the research scientists. In general, engineers within the A.E.C.'s installations and those of its contractors carry over the tendency of engineers in outside industries to keep new engineering knowledge and know-how within the confines of their own organization. And also, as in other industries, the engineers within the classified projects are very often under great pressure to meet deadlines and completion dates and cannot find time to prepare papers for publication. In this field, engineering reputations have been based on processes developed and units built, not on declassified publications.

" . . . there is available within the Commission's installations, such as those at Oak Ridge, far more *declassifiable* information than has yet been released. Much of this will be of great help to you, but can only be obtained if you seek it out and expedite its declassification yourself."

—M. D. Peterson, before Southeastern Section meeting, American Society for Engineering Education, August 28–30, 1950

Concentration of Ores by Induced Activities*

Neutron-induced activity may be used as an aid in ore separation. Ore pickers controlled by radiation detectors may be used to isolate pieces of ore rich in particular elements

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RADIOISOTOPES have been found useful as tracers in the field of mineral dressing. Their use has given much information about the basic processes currently used, such as the flotation of ores. On the other hand, little work has been done on the direct radioactivation of minerals for the purpose of labelling certain elements and of separating the minerals on the basis of these labels.

If some component of an ore could be made radioactive, a concentration of the ore could be effected by separating the active from the inactive pieces.

Recently a radioactive sorting method for concentrating uranium ores was developed by Dr. Christian Lapointe of the Canadian Bureau of Mines (*1*). The apparatus is shown in Fig. 1. Lumps of ore, some of which contain pitchblende, are evenly spaced on a continuously moving belt. A Geiger-Müller or scintillation counter, shielded with lead, is placed above the belt. This counter controls the operation of an electromechanical plunger which pushes the radioactive pieces from the belt. The circuit is designed to actuate the plunger when the counting rate exceeds a predetermined level. This device, currently in use, produces a substantial beneficiation of the ore.

Extension of this procedure to nonradioactive ores could be made by selective activation and detection of the desired (or undesired) constituents. Application to beryl ores has already been demonstrated (*2*). In this case, high-voltage X-rays are used to produce a (γ,n) reaction in the beryllium atoms of the ore. The threshold energies for this reaction are low only for beryllium and deuterium and the process is therefore unique for beryllium ores. In fact the (γ,n) method for beryllium is so selective that it can form the basis for an accurate analytical method (*3*).

In contrast to the extreme selectivity of the (γ,n) reaction, the (n,γ) reaction has breadth and generality. Slow neutrons offer a possibility of a radioactive sorting process suitable for the concentration of a relatively wide group of minerals. A number of variables dictate the degree of neutron activation, and selective activation and detection are possible. Among the large engineering problems which remain to be solved are: a) the magnitude of the neutron flux, b) the practical irradiation time, c) the allowable decay time, and d) the continuous feeding of pieces through the irradiating and sorting units.

Preliminary Estimates

To estimate whether the slow neutron method of concentration is feasible, it is necessary to know how much activity

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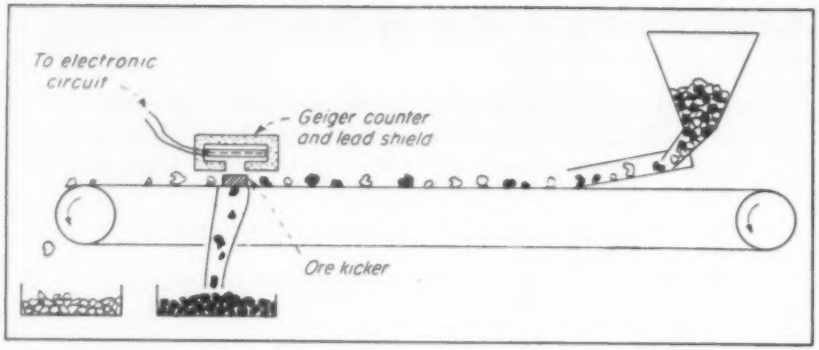

FIG. 1. Lapointe's apparatus for concentrating uranium ores. The kicker pushes the ore sideways off the belt

can be induced in various minerals, and to examine the ores to which such a beneficiation method can be applied. In part, these questions can be answered by simple calculations.

The activity of a given radionuclide depends upon the activation cross section, the neutron flux (or, more properly, the flux density), the number of atoms of the parent nuclide, the time allowed for irradiation and decay, and the half-life of the radionuclide formed.

It is expedient, for purposes of comparison, to choose a given weight of element, and to set arbitrarily the irradiation time and the flux. The decay time is considered later. Since a long irradiation period would not be practical, the irradiation time has been set at one second.

The activities of most of the radionuclides, based on a mass of one gram of the element (consisting of the various isotopes in their natural proportions), and a flux of 10^9 neutrons/cm²/sec, have been published (*4*). To appraise the proposed process, fluxes from 10^6 to 10^9 neutrons/cm²/sec will be considered. Table 1 shows the distribution of radioactivities for different activity intervals at various fluxes. For a flux of 10^6 neutrons/cm²/sec the induced activity is low for most of the elements. To include more elements in the higher activity intervals, a larger flux must be used.

The activities shown in Table 1 are not the counting rates which could be realized from a gram of element. They are the disintegration rates over an angle of 4π, and have not been corrected for absorption of radiation or counter efficiency. The actual counting rates will be considerably smaller. For this reason a disintegration rate of 100 per second was arbitrarily chosen as a criterion of utility. Disintegration rates above this value are easy to detect.

The twenty most promising elements

TABLE 1
Distribution of Induced Activities as a Function of the Neutron Flux

Range of initial activity (dps/gm)	*Flux (n/cm²/sec)* 10^6	10^7	10^8	10^9
	Number of radionuclides			
0.0– 0.1	102	72	48	29
0.1– 1.0	31	30	24	19
1 –10.0	12	31	30	24
10 –10^2	10	12	31	30
10^2 –10^3	4	10	12	31
10^3 –10^4	3	4	10	12
10^4 –10^5	3	3	4	10
$> 10^5$	0	3	6	10

and their activities after irradiation in a flux of 10^6 neutrons/cm²/sec are listed in Table 2 (activities at higher fluxes can be found by direct proportion). Only about half of these elements are of commercial interest in themselves. However, since certain mineral associations recur frequently in nature, the method may be of use for other elements. Gold and lead-zinc ores, for instance, usually contain silver as an auxiliary metal, and may, perhaps, be separated on the basis of the silver content.

There are cases where other circumstances cancel the advantage of favorable geological association. In the case of platinum and iridium, which usually occur together, the platinum ore is not concentratable on the basis of the activity produced in the iridium. The γ radiation from the short-half-life iridium is very soft and partially internally converted. The resulting conversion electrons and the weak γ rays are easily absorbed and the observed activity is small. Similarly, the usual association of tantalum and niobium would be difficult to detect. Ores containing lithium or boron would also be difficult to detect because of the extremely short half-lives of these elements.

Another question to be considered is the effect of gangue elements. The activities of the common gangue elements after activation are shown in Table 3. With the exception of aluminum the activities are low. However, if high fluxes are required, a few of the gangue elements besides aluminum might cause high backgrounds since they may be much more abundant than the elements sought. A point to be stressed concerning Table 3 is the very low activity of both sulphur and oxygen. Hence the activities induced in simple sulphide and oxide minerals will be due primarily to the metallic constituents.

The disintegration rates per gram for various minerals irradiated by a flux of

TABLE 2
The Twenty Elements* Most Susceptible to Slow Neutrons

Element	*Initial activity†* (*dps/gm*)	*Activity after one second decay* (*dps/gm*)
Indium	42,000	40,000
Dysprosium	25,200	25,200
Rhodium	13,200	12,800
Silver	7,840	7,640
Scandium	7,000	6,778
Lithium	2,600‡	1,180
Iridium	2,400	2,400**
Boron	2,200‡	nil
Vanadium	180	180
Europium	61‡	61
Bromine	22‡	22
Aluminum	19	19
Fluorine	18	17
Copper	16	16
Iodine	15	15
Niobium	14§	14
Mercury	11	11**
Manganese	10	10
Cobalt	8§	8
Lutetium	5.5	5.5

* Composed of isotopes in normal proportions.
† Based on a flux of 10^6 slow neutrons/cm²/sec applied to 1 gm of the element for 1 sec.
‡ Essentially a β-emitter.
§ Essentially a low-energy γ-emitter.
** Detection probably difficult; γ's internally converted.

TABLE 3
Neutron-Induced Activities of the Twelve Most Abundant Gangue Elements

Element	*Initial activity††* (*dps/gm*)
Aluminum	19.0
Sodium	0.17
Magnesium	0.140
Potassium	0.015
Calcium	0.005
Silicon	0.005
Phosphorus	0.002
Sulphur	0.0009
Oxygen	0.0004
Iron	0.00001
Carbon	2.0×10^{-10}
Hydrogen	6.5×10^{-11}

†† Based on a flux of 10^6 slow neutrons/cm²/sec applied to 1 gm of the gangue element for 1 sec.

TABLE 4
Neutron-Induced Activities in a Representative Selection of Minerals

Mineral	*Formula*	*Initial activity per gm of mineral per sec irradiation* (dps/gm)*
Albite	$NaAlSi_3O_8$	1,900
Anorthite	$CaAl_2Si_2O_8$	3,800
Argentite	Ag_2S	7.8×10^6†
Arsenopyrite	FeAsS	110
Barite	$BaSO_4$	130
Bauxite	$Al_2O_3 \cdot 2H_2O$	7,400
Brucite	$Mg(OH)_2$	59
Calcite	$CaCO_3$	2.3
Chalcocite	Cu_2S	13,000
Chalcopyrite	$CuFeS_2$	5,800
Chert	SiO_2	2.5
Corundum	Al_2O_3	10,000
Covellite	CuS	11,000
Fluorite	CaF_2	8,800
Galena	PbS	0.15
Gold	Au	860
Gypsum	$CaSO_4 \cdot 2H_2O$	1.7
Hematite	Fe_2O_3	0.11
Kaolinite	$H_4Al_2Si_2O_9$	4,000
Magnesite	$MgCO_3$	41
Marcasite	FeS_2	0.46
Microcline, Orthoclase	$KAlSi_3O_8$	1,900
Pyrite	FeS_2	0.46
Pyrolusite	MnO_2	6,300
Quartz	SiO_2	2.5
Sphalerite	ZnS	370
Topaz	$(AlF)_2SiO_4$	5,500

* Based on flux density of 10^9 $n/cm^2/sec$.
† Decays to 6.8×10^6 dps/gm in 5 sec.

TABLE 5
Yield of Various Neutron Sources
[Taylor and Havens (*5*)]

Neutron source	*Usable neutron flux ($n/cm^2/sec$)*
Pile	10^{10}–10^{12}
Cyclotron	10^8 –10^9
Low-voltage D-D neutron generator	10^5 –10^6
1 gm RaBe	10^4 –10^5
1 curie SbBe 60-d half-life	10^3 –10^4
1 curie PoBe 140-d half-life	10^3 –10^4

10^5 neutrons/cm^2/sec are shown in Table 4. It is seen that not all minerals will be susceptible to concentration even at the high flux on which these calculations are based. Table 4 also shows the very wide range of susceptibility of the typical minerals chosen. The minerals containing silver, aluminum, copper, or manganese are, in general, easily activated by slow neutrons.

It appears, then, that for a slow neutron flux of 10^6 neutrons/cm^2/sec, an apparatus could be constructed which would be capable of concentrating a few ore types such as those containing silver. In general, a higher flux, say of the order of 10^8–10^9 neutrons/cm^2/sec, would be required to concentrate a larger variety of ores.

The Neutron Source

The neutron source used for an ore sorting operation should be relatively inexpensive and require a minimum of maintenance. It must also be capable of delivering a flux of not less than 10^6 neutrons/cm^2/sec. Table 5 shows the usable neutron fluxes for a number of neutron sources (*5*). The corresponding slow-neutron fluxes for these same sources will be somewhat less, depending on source and moderator. A pile is without equal as a neutron source, although at present the cost is far too great. It is possible, though, that in the future, piles will be used for industrial purposes.

The cost and maintenance of a cyclotron seems out of the question for ore-treating purposes alone. The low voltage deuteron-deuteron neutron source is more economical, but the flux obtainable limits its use to a few minerals. The other sources have insufficient yields for these purposes.

There are reactions not mentioned in Table 5 which may be used as neutron sources (*6*). A few yield large neutron fluxes at voltages up to several Mev. Voltages of this magnitude can be ob-

tained with Van de Graaff generators.

The reaction Be^9 (γ,n) Be^8 can be used with an electrostatic generator to eliminate the need for positive ions. Wiedenbeck (7) has shown that, with a 100-μa electron beam, 3.2-Mev X-rays produce a neutron flux approximately 25 times that from a 1-gm Ra-Be source (about 10^7 neutrons/sec in 4π ster-radians). Experiments in this laboratory (8) agree with Wiedenbeck's results; a flux of about 10^7 slow neutrons/cm^2/sec is obtained when the ore is fairly close to the beryllium target.

A linear accelerator has been used in England to initiate the same reaction (9). This accelerator gives a 2-μsec pulse of electrons, and produces very high peak currents. At 3.2 Mev and 100 ma, yields of about 2×10^{12} neutrons/sec per pulse were obtained using a heavy-water target; yields about 30% lower were obtained with a beryllium target. If these neutron pulses are averaged over a period of one second (the repetition rate is the line rate of 60 cps) yields of about 10^8–10^9 can be produced. For industrial applications the (γ,n) reaction may offer a feasible source of moderately high neutron fluxes.

Irradiation Time

Since the half-lives of the radionuclides produced are long compared to the necessarily short irradiation time, activities greater than 100 dps/gm are difficult to produce. The method clearly favors radionuclides with short half-lives. Silver, however, is the only commercially important element having a radionuclide with a half-life less than one minute. Thus the irradiation time should be as long as possible without reducing the capacity of the apparatus; an irradiation period of not more than a few seconds can be tolerated.

An alternative approach is to expose the ore over a longer period of time without slowing down the over-all operation. This requires that more efficient use be made of the neutron sources. It has been shown (8) that the total neutron production measured at right angles to the target increases as the thickness of the beryllium target is increased up to 15 cm. An efficient way to irradiate pieces of ore, then, would be to circulate them around and under a very thick beryllium target, as shown in Fig. 2. This scheme reduces the loss of neutrons from the target and increases the irradiation time.

Selective Detection and Activation

The activity of a piece of ore may be due to more than one of the radionuclides present. Generally there will be one or more predominant activities and several lesser activities. Some method must be used to differentiate among these radiations, since a counter-controlled picking mechanism will be triggered by any of the beta or gamma rays which reach it.

A γ-emitting radionuclide can be picked out from among beta emitters by shielding the detector from the betas. For instance, suppose it is desired to

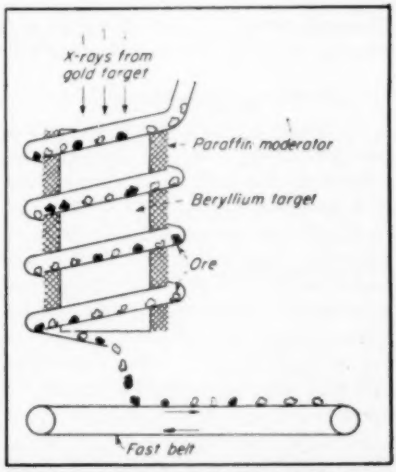

FIG. 2. Circulation of ore around target to increase the time of exposure to the neutron flux

remove clay (aluminum) from a lead-zinc ore containing silver whose beta radiation interferes with the gamma count from the aluminum. A 1,400-mg/cm² absorber will stop the betas, and the sorting can be made on the basis of the gammas from the aluminum. Or the betas may be removed by a strong magnetic field if attenuation of the gammas by absorption is undesirable.

Use of a scintillation counter instead of a G-M counter will help distinguish between beta and gamma radiations. This is because the ratio of the efficiencies of gamma and beta detection is greater for a scintillation counter than for a G-M counter.

If several gamma radiations are present, the activities are not as easy to resolve. A combination of absorbers or a differential pulse-height discriminator might pick out the desired activity.

In some cases the desired radionuclide has a long half-life compared to the half-lives of the other radionuclides in the ore. A short wait until the contaminants have decayed will accentuate the activity of the material to be picked out. The separation of fluorite (12-sec fluorine) from feldspar (2.4-min aluminum) would be aided by this method.

Preliminary Experimental Tests

To obtain a rough idea of the activities produced, a simple experimental apparatus was built. A moving cloth belt was placed directly beneath a Van de Graaff generator. Directly over the belt, at a lateral distance of about one foot from the axis of the Van de Graaff generator, a conventional end-window G-M counter was mounted. Pieces of ore were placed on the far end of the belt and allowed to pass beneath the beryllium target of the generator. A piece of ore spent about 2.5 sec under the target, after which it passed under the counter. The Van de Graaff generator was stopped when the ore was directly under the counter and the counting rate was determined. The neutron flux was not always the same but approximated 10^7 neutrons/cm²/sec. Table 6 shows the counting rates for pieces of various samples 17 seconds after irradiation. Under practical conditions this time could be reduced to a few seconds. The counting rate of those minerals containing short-half-life elements, such as silver or lithium, can be enhanced by employing a shorter time interval between irradiation and counting.

TABLE 6
Activities Produced in Ten Minerals

Specimen	*Weight (gm)*	*Activity above background 17 sec after irradiation (cpm)*
Azurite	15.5	6,031
Bauxite	72.3	6,500
Black manganese ore	22.7	2,439
Bolivian silver ore	24.4	17,920
Cinnabar	41.5	352
Coal	2.1	656
Lepidolite	18.3	1,831
Rhodochrosite ore	11.5	490
Sphalerite	14.8	359
Stibnite	19.0	445

As would be expected, the activities of minerals containing silver, aluminum, copper, and manganese are the largest. Although mercury occurs among the twenty most susceptible elements (see Table 2), the activity of cinnabar is relatively low because the 43-min radionuclide decays by isomeric transition and the detectable activity is low. The activity produced in the coal is due to the ash content.

To eliminate the difficulties caused by the high background of the Van de Graaff, the ore could be transferred from the generator to the counters on a fast belt passing through a narrow

channel in a concrete shield. Such a method would allow a large amount of ore to be processed in a short time.

Use of a Reactor

It is interesting to make a few long-range speculations on the use of a reactor for ore concentration. At present the cost of a reactor is high, but eventually it may come within the scope of a large commercial enterprise.

Since the neutron flux of a reactor is so great, sufficient activity to operate a sorting mechanism would be produced in many ores by merely dropping them through the reactor. If each piece is irradiated for 2 sec and 100 quarter-pound lumps are irradiated simultaneously, the capacity is about 3,000 pieces per minute, or some 500 tons per day. This could be increased considerably by employing several dropping chutes in the same reactor.

The high-flux regions of the reactor could probably not be used for irradiation. Not only would the passing ore absorb neutrons, thus reducing the reactivity, but holes in the central region would allow neutron leakage. The consumption of neutrons by the passing ore might necessitate an extra-large reactor. The dropping chutes could be located just inside the shield where the flux might still be high enough (say 10^9 neutrons/cm^2/sec).

The large tonnage of ore that a reactor could handle would make it useful to the coal industry. Neutron activation would make it possible to grade coal not only according to size and specific gravity, as is done at present, but also according to kind of ash. If the various portions of a coal seam contain different proportions of ash, as well as different proportions of the elements forming the ash, some useful sorting could perhaps be achieved. Furthermore, this type of sorting, in contrast to most current industrial separations, would keep the fuel dry.

Limits of ash analysis for bituminous coal have been determined (*10*). Since the total ash content of such coal is known (7–10%), the activity produced in 1 gm of coal by a flux of 10^9 neutrons/cm^2/sec can be calculated. If it takes a second for a piece of coal to drop through the reactor, an activity of the order of 200 dps/gm would be produced. Quarter-pound pieces of coal would have a disintegration rate of about 20,000 dps. Because of geometrical and absorption losses, only a fraction of these will actually be counted. But the activity appears large enough to be picked out easily.

Application of the same idea to other large-scale mining operations—processing of iron ores, manganese ores, titanium ores, and copper ores—is obvious. A detailed discussion, however, is premature.

* * *

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Radioactive Dust Separation Equipment—II

Development is underway to keep separation equipment abreast of the use of radioactivity. Equipment used in other fields is being adapted; liquid scrubbers, combined with particle-growth apparatus, may attain high removal efficiency

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THE SHORTCOMINGS of dust-separation equipment used on radioactive dusts to date have been discussed in Part I of this series (NU, April, '51, p. 37). These shortcomings have prompted the Atomic Energy Commission to encourage extensive development programs devoted to the dust removal problem.

Several universities are participating in short- and long-range research programs for the AEC. The University of Illinois (H. F. Johnstone) is investigating theoretical considerations in deposition of gases from stacks and new techniques for dust removal. The University of Rochester (H. Laskin) is doing research in the detection and measurement of toxic smokes and their resulting effects. The Harvard School of Public Health (Philip Drinker) is undertaking an equipment development program to adapt and develop commercial equipment.

Many commercial concerns are also undertaking development programs. For example, the Kellex Corporation is undertaking development work in liquid scrubbers, sonic agglomerators, and condensation techniques. A. D. Little Company is undertaking the development of filters. American Air Filter Corporation is working to develop filters and filter installations.

The AEC has organized a board of consultants to assist in setting up some of these programs. Finally, present atomic installations themselves are actively engaged in their own particular problems, with development and adaptation to suit their respective needs.

EQUIPMENT BEING DEVELOPED

This article is devoted to the equipment and techniques currently being studied in the various development programs. Possible future steps in developing dust separation equipment will be considered in Part III.

The first step in any development program is the adaptation and improvement of present equipment. Such efforts are actively under way in the field of filters where such things as higher efficiency, humidity-resistant and corrosion-resistant papers, and papers made of purely domestic materials are vitally needed. Also, in the field of filter installation, equipment which can be remotely handled, repaired and replaced is being developed.

The most promising developments in present equipment have been in the field of deep-bed filters. New materials, such as Fibreglas, are being tested in pilot-plant studies and are giving considerably higher efficiencies and lower pressure drops. These new filtering media may also have a considerably increased life because of greater capac-

ity to hold dust before excessive plugging is encountered. Preliminary data has shown as much as a ten-fold increase in efficiency for the same pressure drops (4–6 in.), or the same efficiencies with a much lower pressure drop, below 1 in. While not circumventing the problems of equipment size and inability to dispose of the collected dust, the deep-bed filter comes closest to achieving many of the other desired results than most of the other equipment being investigated.

Electrostatic precipitation is also being developed and investigated further. The major development is toward remote operation and maintenance of the precipitation equipment.

Equipment and techniques currently being employed in other fields are also being studied. Those that can possibly be of use with radioactive dust are discussed in the following pages.

Liquid Scrubbers

Liquid scrubbing provides a means for continuous removal of dust from the equipment in which it is concentrated. The dust, after being removed from the air, is disposed of in a liquid stream. This would be, in most cases, a negligible addition to other liquid wastes emanating from the plant or laboratory. In addition, liquid scrubbers utilize high velocities and thus require little residence time. This makes possible small, compact equipment, easily designed and scaled up from test data and other installations.

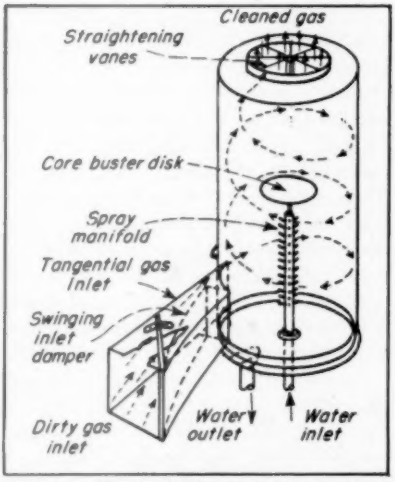

FIG. 7. Pease-Anthony cyclonic-spray scrubber

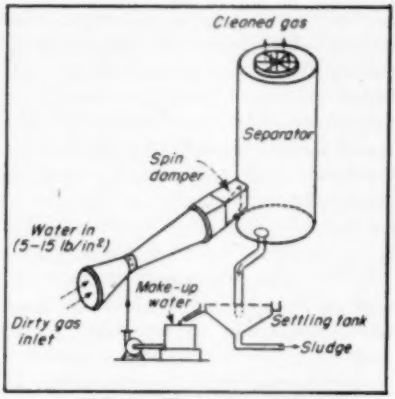

FIG. 8. Venturi scrubber

Three types of liquid scrubbers are in evidence today: spray towers, Pease-Anthony venturi scrubbers, and Peabody perforated scrubbers.

Spray towers. The spray tower (Fig. 7*) utilizes fine spray to collide with the dust particle; the dust is removed with the spray drop. However, the spray tower has been wholly unsatisfactory for submicron particles because the effective area for collision is reduced by the tendency of the small particles to remain in the slip stream and circumvent the spray particle (*20*). This type of tower is, therefore, not being developed, except in conjunction with other collection phenomena.

Venturi scrubber. The Pease-Anthony venturi scrubber (Fig. 8) has not been applied to radioactive dust problems specifically. However, test work

* Figures 1–6 appeared in part I of this article.

has been done on materials very similar in size. The venturi scrubber utilizes the high velocity of gases in the venturi throat to shear the injected water into tiny spray droplets. The violent agitation caused in the throat intermixes the gases and spray droplets and increases the opportunity for the dust to collide with the spray droplets. The spray droplets are then centrifugated out in a Pease-Anthony spray tower. Test results indicate 90–98% efficiency can be achieved on essentially small dust (*21*). However, this is accomplished at very high pressure drops, 14 or more inches of water. The venturi scrubber definitely shows possibilities where small installations are necessary and pressure drops are unimportant.

Peabody scrubber. The Peabody perforated scrubber employs the high impingement velocities of gases as they go through orifices in water-covered plates to separate and trap the particles. The plate consists of two parts: a perforated sheet having from 600 to 3,000 holes/ft², and impingement baffles mounted above the sheet and arranged so that a baffle is located directly above each perforation (Fig. 9).

Dust-laden gas enters the perforated plate and is broken up into a great number of high-velocity jets. These jets are shot against the baffles, and, since the baffles are at the approximate vena-contract of the stream, the jets strike at the maximum velocity. The particles which impinge on the plate are driven into the liquid, where they become trapped and are flushed away.

The performance of the Peabody scrubber on a submicron dust comparable in particle size and distribution to radioactive dust has been ascertained to be very small (*9*, *22*, *23*), probably less than 5% per plate. The extremely low value by no means suggests that the plate-type scrubber is an unsatisfactory device, but instead demonstrates the extreme difficulty in removing fine dust particles with conventional equipment. It indicates that, with submicron dust, attempts to increase efficiency of the scrubber by increasing its centrifugal action are entirely useless.

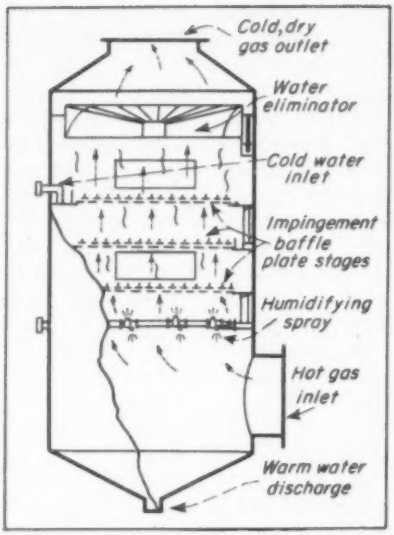

FIG. 9. Multi-stage Peabody perforated plate scrubber

Particle Growth

Conventional types of equipment effect removal of dust by impinging the particles against a surface or trapping them within small interstices. The size and weight of the dust particles are critical; the larger the particles, the easier it is to effect their removal. Thus, enlargement of particles can produce higher efficiencies than are normally obtainable in conventional equipment. Coupled with the continuous removal and compact size of liquid scrubbers, particle growth could be used to advantage.

Growth in particle size can be accomplished in two ways. Several particles can be agglomerated to form one bigger one, or water can be deposited on a particle by condensation to make it bigger. The former case applies to

the sonic agglomerator and will be considered later.

The latter case has also been developed and is being investigated fully now. Of the various methods proposed for inducing condensation, the two under investigation are injection of steam into a cool gas stream, and adiabatic conversion of internal energies of the gases into high velocities.

Condensation by steam injection. Under the proper thermodynamic conditions (Fig. 10), injection of steam into a cold dust-laden gas stream can result in conversion of around 8 to 10% of that steam into condensed droplets. These droplets would preferentially seek out the dust upon which to condense. This can increase the weight of a particle 100 times or more. Under the supposition that a dust was being treated which had the order, or magnitude of concentration, of atmospheric dust, i.e., around one grain per 1,000 ft^3 of gas, the injection of 0.1 lb of steam per lb of air would enlarge the submicron particle to around 5 μ in diameter, assuming a theoretically even distribution of the condensed moisture over all the particles. The dust-laden air could then be passed through conventional scrubbing equipment capable of handling the enlarged particles, but which would ordinarily be relatively ineffectual on submicron particles.

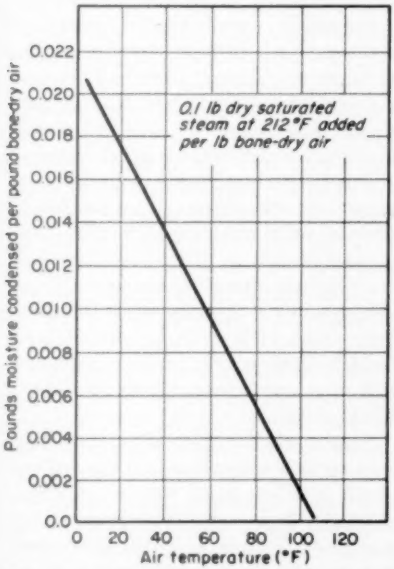

FIG. 10. Moisture condensed plotted against initial air temperature

Experimental work to ascertain the effectiveness of steam injection in improving the efficiency of conventional scrubbing equipment is being carried out, but the data collected are not available for general publication (*7*). In lieu of more specific information, however, certain generalizations enable one to predict the action of steam injection in improving scrubbing efficiency.

The Peabody scrubber can be used as an example of a typical commercial scrubbing unit. Without particle growth, its efficiency is practically nil on submicron dust. Plates are available for this unit with hole diameters as small as $\frac{1}{16}$ in. which operate under a pressure drop of 4 in. per plate. Even this fine a plate is not efficient on submicron dust.

Now adapt the Peabody scrubber for steam injection as shown in Fig. 11. The introduction of 0.1 lb of atmospheric steam (212° F) per pound of saturated dust-laden gas (initial temperature, 70° F) changes, according to Fig. 10, about 8% of the steam to condensed moisture. This would provide a fifty-fold increase in particle diameter. The resulting 5-μ particles could easily be removed by a plate like that described with 100% efficiency.

The assumption of even distribution of water over all the particles is not a valid one, however. Studies made in the distribution of the condensed water (*4, 9, 22–25*) show that the water preferentially wets the larger particles, or favors those which are first to be wet. The preferential wetting of the larger

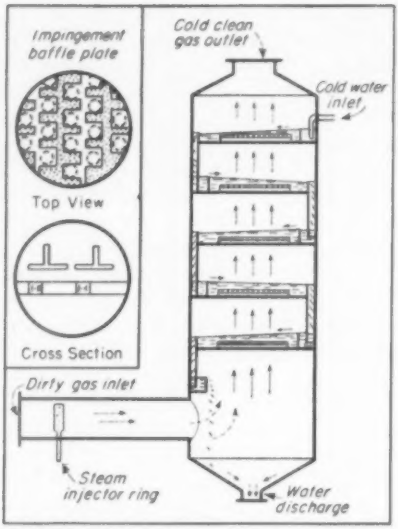

FIG. 11. Five-stage Peabody perforated plate scrubber adapted for steam injection

particles is in accordance with the lower vapor pressures associated with the larger radii of curvature, as given by (*9*)

$$\ln p/p_s = 2\gamma/RTW\tau$$

where p is the actual pressure of the vapor, p_s is the saturation pressure at the existing temperature T, γ is the surface tension at temperature T, R is the gas constant for the vapor, W is the density of the liquid, and τ is the radius of curvature of the liquid surface.

It is estimated that from 70 to 90% of the particles will be preferentially wet to a major degree, the remainder remaining dry or not significantly increasing in size.

With a single steam injection stage before the scrubber as shown in Fig. 11, the action of the five plates would be to remove the particles which were the greatest in size on the first plate, with the efficiency of each plate rapidly diminishing and approaching as a limit the efficiency of around 5% for the dry dust particles. It would be found that the over-all efficiency of removal would not be significantly higher than the efficiency with which the particles were preferentially wet to a major degree. Thus, the limiting efficiency of the scrubber would not be materially increased by increasing the efficiency of the plate (just as was the case in untreated dust), but rather by increasing the number of steam-injected stages. The latter is accomplished by introducing points of injection between each plate stage (not shown in Fig. 11). This would serve to wet the particles not wet by the previous stage, this injection occurring after the wetted particles were first removed.

In this manner, each stage would operate at the limiting efficiency governed by the per cent of particles wet by each steam injection. Assuming that 90% of the particles could be wet with each stage, the total efficiency of a five-stage scrubber would be 99.999%. Thus, the use of steam injection in conjunction with a conventional plate scrubber might be able to achieve high efficiencies which are not obtainable in any other way except by filtration or electrostatic precipitation. Development would be aimed at reducing the plate pressure drop, increasing the percentage of particles wetted by each steam injection stage, and increasing the number of steam injection stages.

Interstage cooling is necessary to effect the thermodynamic conditions necessary for condensation to take place in the next stage. This interstage cooling requires extensive cooling coils and accompanying equipment, but nevertheless can be justified when the result is high efficiency, compact equipment, and continuous removal of dust in a liquid stream.

Steam ejector nozzle. One significant experiment which was carried out under the category of condensation through conversion of energy is described by P. J. Schauer (*9, 23*) in work on submicron dust. The dust-laden gases were passed through a special

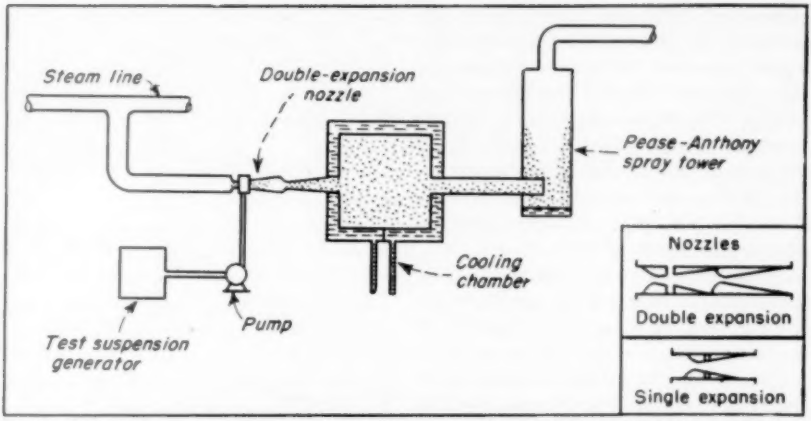

FIG. 12. Schauer's apparatus for producing condensation by adiabatic expansion

type of steam ejector which was designed to act both as a prime mover of the gas stream and also as a means for producing condensation about the dust particles by virtue of the adiabatic expansion of the stream. Schauer obtained extremely high efficiencies.

Figure 12 shows the test equipment employed to carry out the experiments. Tests were conducted on many different types of nozzles, but the two most significant tests were accomplished with a single-expansion nozzle and a double-expansion nozzle. The inset in Fig. 12 shows the shape of each. Steam at a gage pressure of 44 lb/in² was allowed to expand through the nozzle under test down to atmospheric pressure. The nozzles were equipped with inlet ports in the first expansion stages.

The test suspension had a particle diameter of 0.3 μ and was essentially monodispersed. It was either sucked into the single-expansion nozzle through the inlet ports and allowed to mix with the steam, or pumped into the double-expansion nozzle at 22 lb/in². A ratio of about 1 part dust-laden gas to 2.3 parts steam by weight was employed. The condensation so produced was stabilized by allowing the gases to pass directly into a chamber which was kept cold by cooling water circulating around its outside walls. The resulting mist was removed in a regular Pease-Anthony spray tower. The nozzles were designed from data and visual observations obtained from experiments on square nozzles equipped with glass sides. These were designed to duplicate the experiments initially conducted by J. I. Yellott (*24*, *25*).

With no steam at all, the dust suspension was removed by the Pease-Anthony scrubber with 0% efficiency. With saturated steam, the single-expansion nozzle produced 98% efficiency in the scrubber. With the double-expansion nozzle, the efficiency was found to be 99.9%. It was concluded that, in the single-expansion chamber, most of the steam had condensed before mixing with the dust suspension.

The results clearly indicate the effectiveness of condensation through conversion of energy. However, the necessity of pumping the gases in at high pressure without subsequent recovery of the work put into the system demands such a high power consumption that the technique must be limited to processing small quantities of gases.

Condensation by sudden cooling. This is a particularly useful method for

improving efficiency where extremely hot and humid gases are to be treated; steam injection will not work because the thermodynamic conditions are wrong. Sudden cooling is an inefficient method for producing condensation since most of the water condenses on the cooling surface, but enough condensation takes place on the particles to effect considerable growth.

While there has been no systematic investigation of condensation through sudden cooling, qualitative reports of improvement in efficiency have been forthcoming. The most impressive indication of the ability to produce condensation by sudden cooling was reported by P. J. Schauer (*23*) in an experiment to test condensation by adiabatic expansion. When conditions were purposely imposed which negated the effect of adiabatic expansion, condensation was achieved solely by a cooling chamber. A removal efficiency of 70% was obtained in a Pease-Anthony spray scrubbing tower; an efficiency of 0% had been achieved without the presence of moisture.

Agglomeration with sound. Agglomeration of several dust particles into a single larger one is a form of particle growth and results in a heavy agglomerate which can be centrifugated. However, the technique for agglomeration is quite different than that used in particle growth. The dust particles are agglomerated by the use of sound waves introduced into the gas stream from a source of high-intensity sonic output (Fig. 13). The sound waves cause the particles to vibrate violently in the gas stream, with resultant collisions and agglomeration.

Sonic agglomeration has proved effective in many commercial dust problems, developing high efficiencies at low pressure drops and employing relatively low power consumption. However, when tested on simulated radioactive dusts, several disadvantages were demonstrated. First, concentrations of dust must be high for the sonic agglomerator to have any effect, around one grain per ft^3; this concentration is above those usually involved in radioactive dust problems. Second, the use of artificial loading to produce the necessary concentration for agglomeration, usually accomplished by injection of water droplets, has failed for the following reasons: The number of droplets which can be practically injected into a gas stream is not sufficient to offer a high probability of impingement. The very water which is injected is subjected to agglomeration by the intense sound waves. Also, the water injected is usually carried along as a suspension in the gas. Hence, the dust cannot diffuse through the water particles as it would through a filter, which greatly decreases its probability of collision.

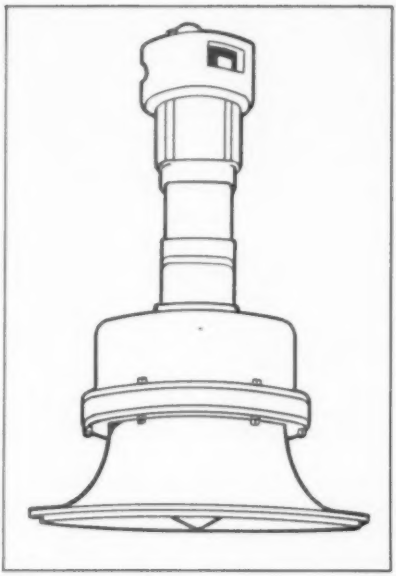

FIG. 13. Typical form of commercial sonic generator

Work in the field of ultrasonics is still in preliminary stages as applied to radioactivity. New ways of employing sonic vibrations are being considered.

Summary of Equipment under Development

The separation equipments under development show promise of possessing the following major advantages over those presently employed:

1. Through the use of liquid scrubbing and collection techniques, continuous removal of the collected radioactive dusts can be achieved. Such a means for removal does away with the secondary handling and remote operating techniques necessary with filters. The use of a liquid to contain the dust particles enables simple concentration methods to be employed. The bulk of the liquid can be made very small. Liquid collection can provide for a completely closed system until the liquid reaches the proper disposal point.

2. The use of steam injection shows promise of achieving efficiencies higher than any obtainable with present equipment. It may be possible to achieve the desired removal of all but one particle in one million through the medium of particle enlargement.

3. The separation equipment under development shows promise of being considerably more compact than any equipment now used. The lack of dependence upon residence time and slow velocities of the gases makes this possible. Reductions to $\frac{1}{6}$ the diameter of present equipment has already been achieved by the liquid scrubbers tested.

4. The equipment under development can be used for handling wet, corrosive gases, which ordinarily cause prohibitive wear in present equipment.

5. The equipment under development presents no particular problems in maintenance or decontamination. The surfaces of the equipment can be designed for easy cleaning if it does become necessary to decontaminate them for maintenance purposes.

Disadvantages. There are several disadvantages that accrue with the equipment under development.

1. Liquid scrubbers will necessarily operate with high pressure losses when achieving high efficiencies. It should be remembered, however, that present equipment, with the exception of paper-matte filters, could not achieve these high efficiencies if employed in series without employing at least the same pressure drop.

2. The use of equipment dependent upon the condensation phenomena to achieve high efficiencies is limited to operations in which the proper thermodynamic conditions can be achieved and steadily maintained. Extreme variable conditions which could not be controlled ahead of the entrance to the condensation chambers would result in unsatisfactory operation.

3. Condensation techniques are necessarily inefficient operations. As such, they require high power consumption, not only in pressure losses but also in the power consumed in the steam generators and interstage coolers.

4. There is a definite limitation to the amount of steam which can be converted into condensed moisture because of the thermodynamics involved. Therefore, high concentrations of dust particles do not lend themselves as well to injection of steam because there is not enough condensable water to go around. The higher concentrations will result in more unwetted particles, thus requiring more stages to effect the desired concentration.

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Nuclear Science and Engineering School Curricula*

Here is an educator's judgment on the future demands nuclear technology will make on scientific personnel and how the engineering school can best prepare its students to meet them

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PRIOR TO 1940, our over-all manpower pool had sufficient reserves to permit the development of engineering education in a laissez-faire manner without detriment to the nation. Today, however, with the prospect of maintaining an economy under the strain of long-term military preparedness, even such a special problem as the teaching of the nuclear sciences has to be considered in view of the nation's demands.

As can be seen on the next page, no fewer than fifteen important types of scientists and engineers are involved in the development of nuclear energy and its associated applications. This discussion concerns the training of three of these types, the nuclear engineer, the nuclear physicist, and the engineering physicist.

Nuclear Engineers

As a basis for this discussion, it is proposed that *nuclear engineering* be defined as that branch of engineering concerned primarily with the design, construction, and operation of reactors.

At present, only one school, North Carolina State College, offers a *degree* in nuclear engineering.† Why have the engineering colleges been loathe to institute this degree, one which, at its face value, should be very popular?

Among the many reasons why they have not done so and why they should not do so in the immediate future are: (1) the limited demand for nuclear engineers, (2) the inherent difficulty of the subject for an undergraduate curriculum, (3) the sound alternative approaches to the problem, and (4) the restrictions imposed by security regulations upon teachable subject matter.

Except for the low-power reactor planned for North Carolina State College, all nuclear reactors in the United States at present in operation or construction are under the auspices of the Atomic Energy Commission. Dr. Borst of the Brookhaven National Laboratory has estimated that about 2,000 engineers are required by the AEC.‡ To maintain this level, he sets the replacement rate at 70 per year. Based upon the military rule that annual increments of about 5% are required to maintain the regular army officer corps at strength, Dr. Borst's estimate seems rather low. He may have been influenced by the fact that the average age of present AEC personnel is lower than in most large government or industrial organizations. A more gener-

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* This article is based on a paper read at the 117th Annual Meeting of the American Association for the Advancement of Science, Cleveland, Ohio, December 29, 1950.

† Clifford K. Beck, "Undergraduate Nuclear Engineering Curriculum at North Carolina State College," NUCLEONICS, Jan., 1951.

EDITOR'S NOTE: It has recently been announced that a graduate degree in nuclear engineering will be offered by Massachusetts Institute of Technology.

‡ Lyle B. Borst, "Engineering Opportunities in Atomic Energy," NUCLEONICS, Dec., 1949.

Technically Trained Personnel Involved in the Development of Nuclear Energy and Associated Activities

Professional Title	*Activity*
1. Geologists (geological engineers)	Location of radioactive ores
2. Mining engineers	Recovery and processing of ores
3. Metallurgical engineers	Processing of nuclear fuels (radioactive metals) Development of materials for use in reactors and nuclear power plants
4. Chemical engineers	Processing raw materials Separation of radioactive isotopes Disposal of radioactive wastes
5. Nuclear chemists	Basic and applied researches Development of chemical processes for separation of active materials
6. Nuclear physicists	Basic and applied researches Fundamental reactor design
7. Engineering physicists	Instrumentation, including radiation detection instruments Health physics (monitoring of radiation exposures)
8. Mechanical engineers	Reactor design Heat exchanger design Mechanical power-plant design
9. Electrical engineers (power and electronics)	Electrical power-plant design Control systems design Instrument design
10. Civil engineers	Over-all plant construction
11. Mathematicians	Reactor calculations
12. Doctors (radiological specialists)	Treatment of radiation exposures
13. Biologists	Basic researches
14. Physiologists	Basic researches
15. Nuclear engineers	Design, construction, and operation of reactors

ous estimate might be to assume an annual demand for 100 engineers in the AEC. And only a fraction of these would be *nuclear* engineers.

The armed services also employ nuclear engineers. As supplied by the Armed Forces Special Weapons Project, the estimates of the number of individuals with training in nuclear science required annually by the armed services are approximately as follows:

Officers	*Civilians*	*Total*
Nuclear physicists:		
40	80	120
Nuclear chemists:		
20	40	60
Nuclear engineers:		
25	50	75
Radiologists and biophysicists:		
30	60	90

Aside from the AEC and the armed services, the only current demand for nuclear engineers comes from a few large industrial concerns operating under AEC contract, such as General Electric, Westinghouse, and Carbide and Carbon. Their annual requirements, I surmise, are small. The traditional policy of these companies has been to select men from within their own organization and give them special training.

My conclusion is, therefore, that the present annual demand for graduates in nuclear engineering would be of the order of 100 ± 50.

In 1949, the 141 accredited engineering schools in the country graduated 6,000 civil, 4,000 chemical, 10,000 elec-

trical, and 11,500 mechanical engineers. On these terms it is obvious that, except for an occasional experiment like that at North Carolina State, there is no point in the engineering schools' rushing into teaching nuclear engineering.

How does all this lead to the thesis that nuclear engineering is not suited to an undergraduate curriculum? To be worthy of the name, the nuclear engineer should have a thorough understanding of nuclear physics, of statistical mechanics, and thermodynamics. He should know something about metallurgical and mechanical engineering. He must know something about electrical power plants and enough about electronics to understand the instrumentation required in the operation and control of nuclear reactors. This is a program requiring the experience and intellectual power normally reached only by graduate students and is far too ambitious for an undergraduate.

Nuclear physics for all engineers. Rather than institute a new branch of engineering* in view of the present state of reactor development, engineering students should be required to take an elementary survey course in nuclear physics in place of one of the electives in the standard undergraduate engineering curriculum.

A trend in this direction has started. Of the 70 largest engineering schools, 56 already offer an elective one-semester course in nuclear physics. Of these schools, 7 *require* such a course for all engineers. A number of others require the course for specific engineering degrees, particularly for those in engineering physics and electrical engineering.

The program I propose is practical and would fit smoothly into the present scheme of engineering education. Unlike a curriculum leading to a degree in nuclear engineering, it would require no great change in present faculties.

Graduate work in nuclear engineering. The time will come when practices in reactor design and construction have become sufficiently standardized to make the rather widespread offering of graduate degrees in nuclear engineering both reasonable and desirable. For the immediate future, the sound approach appears to be to leave reactor development to the team composed of nuclear physicists, chemists, and various types of engineers. By this generalization, I do not condemn the commendable inauguration of graduate work in nuclear engineering in a few strategically located schools.

Many schools have not instituted degrees in nuclear engineering because of the restrictions on subject matter imposed by security classifications. Recent declassification of the technical descriptions of some low-power reactors somewhat alleviates these difficulties.

Nuclear Physicists

Most likely to be in short supply in the exploitation of nuclear energy are the nuclear physicists. Dr. Lawrence Hafstad, the AEC's director of reactor development, recently estimated that there are fewer than 350 qualified nuclear physicists in the country. Some figures on the numbers and current production of Ph.D.'s in physics are tabulated on the opposite page.

In the July, 1950, *Scientific American*, Dr. M. H. Trytten indicates that the annual number of persons graduated from college who possess the basic intellectual capacity to do acceptable work for the doctor's degree in science is not much greater than the number of Ph.D.'s actually being turned out annually by the universities. The conclusion is inescapable, then, that graduate study in nuclear physics (and nuclear chemistry) should be restricted only by the availability of faculties

* EDITOR'S NOTE: The author made a study of the catalogs of the 70 largest engineering schools and found no less than 26 different branches of engineering in which undergraduate degrees are offered.

competent to offer the instruction and of students qualified to undertake it.

Engineer-Physicist Personnel

There are two other classes of personnel who might also in a sense be considered "nuclear" engineers or physicists. One category includes those engaged in the design and production of the wide variety of instruments needed for detecting and analyzing nuclear radiations. The other consists of those primarily concerned with health physics, that is, with the protection of human beings against harmful effects of nuclear radiation.

In the first category, there are at present two primary sources of personnel. The first and very obvious source is the electronics engineer; the second source is the engineering physicist.

Electronics engineer. A competent electronics engineer familiar with the phenomena of nuclear radiation and a little on-the-job training should soon be at home in the design and production of radiation-detection equipment.

Engineering physicist. As the use of radiotracer techniques is increased, there will be a growing demand for individuals trained basically as physicists but who have, in addition, some comprehension of engineering methods and electronic techniques. The training required by them is most nearly approximated by that now given in engineering schools under the title "Engineering Physics." The degree in Engineering Physics has been offered for about two decades. Of the 70 leading engineering schools, some 17 are currently offering this degree with an annual output as of 1949 of about 350.

Health physicist. Besides a knowledge of the fundamental principles and methods of physics, the health physicist should have a general appreciation of nuclear physics, radiation, and nucleonics instrumentation, at a level somewhat above the elementary survey course.

The ideal training for the health physicist appears to be the bachelor's or master's degree in engineering physics, plus some on-the-job apprenticeship or specialized training such as might be obtained in large industrial concerns or the training schools of the AEC.

The number of health physicists required will probably remain comparatively small. An annual output on the order of 100 or 200 should certainly take care of the immediate future.

Educational Degrees

	Doctors	*Masters*	*Bachelors*	*Total*
Number of physicists as of 1945 (from National Roster of Scientists):	2,622	2,613	4,069	9,284
Degrees granted in physics (reported by U. S. Office of Education):				
Year				
1949	266	841	2,828	3,935
1948	198	706	2,126	3,030
1946	61			
1945	38			
1941	187			
1940	138			

Distribution of physicists by employment (1945):

Colleges and universities	—4,000
Industrial laboratories	—3,000
Federal government agencies	—2,000

Conclusions

At this state in the development of the applications of nuclear energy, the establishment of a new branch of engineering called nuclear engineering by engineering schools is neither desirable nor necessary.

Members of engineering school faculties should be on the alert to identify and encourage potential candidates for doctoral work in the nuclear sciences.

Finally, engineering-school administrators should seriously consider increasing their facilities for teaching engineering physics to meet the increasing demands of the atomic energy field for versatile personnel. —END

BOOKS

Sourcebook on Atomic Energy, by Samuel Glasstone, D. Van Nostrand Co., Inc., New York, 1950, 546 pages, $2.90.

In many respects, this is one of the most curious books ever put before this reviewer.

Certainly no more convincing evidence of the fact that nuclear knowledge lies in the hands of groups and organizations rather than individuals could be presented than this volume. The origin of the book is a request for a comprehensive sourcebook for authors and editors, and the Atomic Energy Commission has responded to the request by sponsoring the assembly of this book.

The author, Dr. Glasstone, has an enviable reputation for texts in physical chemistry, and he need not feel worried about his reputation continuing, even though this must have been the hardest task he ever faced. It is the fact that the author, whose training and experience have been in a different field, has done so well that surprises and indeed sobers the reviewer, who has spent so much of his life as a nuclear physicist.

The title is somewhat unusual and the question arises as to who needs the book. At the price one can readily answer "anyone"—and in a sense this is true. There is no abstract mathematics, and interest has not been sacrificed to information. It should be in every scientific library and public library, and anyone connected with teaching physics or chemistry will be grateful for the availability of its contents.

On the other hand, those already experienced in nuclear physics, radiochemistry, or radiobiology will look beyond this book. For example, a student setting up a Geiger counter for a routine experiment in radiobiology will not be satisfied with the chapter on the measurement of radioactivity, nor will a teacher of nuclear physics be satisfied with the chapter on *Nuclear Transmutation and Artificial Radioactivity.* In spite of this statement, however, the thoroughness with which the material has been compiled guarantees that even the expert will gain information on his subject.

Apart from four introductory chapters on atomic structure, there are chapters on the following subjects: *Natural Radioactivity, Measurement of Radioactivity, Nuclear Radiations, Isotopes, The Acceleration of Charged Particles, Nuclear Transmutation and Artificial Radioactivity, The Neutron, Nuclear Structure and Nuclear Forces, Nuclear Fission, The Utilization of Nuclear Energy, The New Elements, The Uses of Isotopes, Cosmic Rays and Mesons, Radiation Protection, and Health Physics.*

Each chapter is treated simply, yet thoroughly, and a feature is made of the description of the origins of research work in each subject. Thus there are pictures of the first microgram of plutonium compound ever isolated and the record of the neutron intensity in the first chain reaction. Many instances such as this make the book of great value from the historical point of view.

With the wealth of expert advice available, one would expect no errors, and this is in general true. Nevertheless, Figure 6.3, in which the collecting electrode of an ionization chamber is grounded, should be changed in the next printing.

It is to be regretted that the recent declassification of actual reactors came too late to be included. This added material would strengthen the book.

To sum up—this is a highly valuable, well-written, and reasonably priced book. It can be recommended readily to scientific and educated lay readers.

—Ernest C. Pollard
Sloane Physics Laboratory
Yale University

Progress in Nuclear Physics, Volume I, edited by O. R. Frisch, Academic Press Inc., New York, 1950, vii + 224 pages, $6.80.

This volume contains eight review articles written by specialists in various fields of modern nuclear physics.

Two papers on particle accelerators start the series; one on cyclotrons by T. G. Pickavance, and one on transformer-rectifier sets and electrostatic generators by R. L. Fortescue. The cyclotron paper emphasizes f-m cyclotrons; simple theory of phase and orbital stability is given, followed by descriptions of typical magnet designs, radio-frequency systems and accessories, with tabular comparisons of the various large machines under construction and in use. The article by Pickavance discusses electrostatic generators with respect to general over-all design, followed by some aspects of the problems of voltage breakdown in accelerating tubes, ion source performance, and voltage stabilizers.

The third article is perhaps the best in the book. It concerns photographic-emulsion techniques, and is written by Professor Rotblat. The treatment is thorough and instructive, yet lucid and readable. The author has made the best of the graphic opportunities afforded by his subject, and has reproduced some very striking illustrative photographs of track records of nuclear events.

The next article deals with electronic circuits for nuclear detectors, and is written by G. G. Scarrott. Starting with a discussion of positive and negative feedback, the author proceeds to outline the operation of actual circuit elements such as trigger circuits, delay lines, pulse amplifiers, discriminators, coincidence circuits, and scalers—both scale of two and scale of ten.

T. H. R. Skyrme's paper on the theory of beta decay should be a welcome modern supplement to Konopinski's well-known review of 1943, although the emphasis is on pure theory, and numerical data are eschewed. The beta-ray theme is carried further by the subsequent article by P. E. Cavanagh, which deals with beta and gamma-ray spectrometry from the experimental standpoint. The comparison of various kinds of spectrometers with respect to aperture and resolution is followed by a discussion of gamma-ray spectrometry, which does not, however, extend to the use of scintillators.

The seventh paper ("The Szilard-Chalmers Process" by H. A. C. McKay) injects a whiff of chemistry into what is otherwise a book of fairly pure physics. The mechanisms of separation from parent molecules of "hot" atoms, either as a result of neutron capture or transitions from metastable nuclear levels, are discussed. The author successfully leaves the reader with the impression that there is much here that is not understood.

The final paper is written by P. M. Cassels, and is concerned with the scattering of neutrons in crystals. The theory is developed in an organized fashion, starting with scattering by a single nucleus and generalizing progressively to include nuclei in crystals, the effect of isotopic mixtures, the effect of spin, and the effect of finite mass. A treatment of this kind has been needed for some time. Salient experimental results are described in the final part of the article.

This book is not intended for the experts, and indeed the experts will find

that the papers in their particular field are inclined to be somewhat superficial and in some cases already dated. The real value of the book is for the informed nonexpert, or the would-be expert. Such a reader will obtain a general orientation from the survey article, and will then be at liberty to use the excellent bibliographies (185 references for Rotblat's article!) to delve deeper if he so desires. Typography and figure reproduction are first class.

—A. H. SNELL

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Ionization Chambers and Counters, by D. H. Wilkinson, Cambridge University Press, 1950, ix + 266 pages, $4.50.

This book, one of the Cambridge Monographs on Physics, is a welcome addition to the literature on ionization chambers, proportional counters, and Geiger counters.

While not as large a book as the one written by Rossi and Staub bearing the same title,* it is every bit as thorough in treating a subject of more limited scope. Whereas Rossi and Staub have given a wealth of constructional details and have described the tests made with various counters for many applications, Wilkinson has limited his discussions more to the physics of chambers and counters. He has concerned himself with describing what goes on in a counter from the instant an ionizing particle enters until the last ion is collected. This he has done, thoroughly and simply.

The organization is good, and the style is clear and straightforward. Dr. Wilkinson has the ability to communicate his ideas in an easily understood manner—occasionally with an undercurrent of humor. The bibliography includes the following reference: "Gilbert, W. S., and Sullivan, A. (1885), Mikado."

After a brief introductory section, Chapter II discusses ionization in gases. Chapter III is concerned with electron and ion mobilities, electron attachment, recombination, and multiplication. Chapter IV, on the Electrostatics of Pulse Formation, is an excellent treatment of the wave forms to be expected from the motion of electrons and positive ions in chambers of parallel plate and cylindrical geometries. The effects of varying amounts of differentiation of the waveforms are shown in a series of graphs. Chapter V is devoted to ionization chambers; current chambers and slow-pulse chambers are treated briefly, but the emphasis is on fast chambers and their application. Chapter VI, on proportional counters, includes an excellent discussion of the statistics of multiplication and the consequent effects on the energy resolution of such counters.

Chapter VII presents the theory and practice of Geiger counters; though the longest chapter in the book, it would have to be considerably longer for this reviewer to follow readily. Some of the concepts should be explained more fully; too much time is required in thumbing through previous sections to find the meaning of symbols. The author leaves one with the feeling that the theory as presented does explain the known facts about Geiger counters quite well. It is the reviewer's opinion that some modification will be required to explain recent data on the large fraction of the Geiger pulse that is apparently due to electron motion.

The last chapter deals briefly with the statistics of counting, chiefly the effect of noise on a pulse distribution.

The book is nicely printed and well illustrated. It is remarkably free from errors. It is highly recommended to

* "Ionization Chambers and Counters: Experimental Techniques" (Div. V, Vol. 2, of National Nuclear Energy Series), by Bruno Rossi and Hans H. Staub, McGraw-Hill Book Co., Inc., New York, 1949.

anyone wishing a deeper understanding of three of the commonly used tools in a nuclear physics laboratory.

—W. H. JORDAN
Physics Division
Oak Ridge National Laboratory

BOOKS RECEIVED

Advances in Biological and Medical Physics, Vol. II, edited by John H. Lawrence and Joseph G. Hamilton, Academic Press Inc., New York, 1951, xi + 348 pages, $7.80. (Vol. I of this series was published in 1948.)

High-Frequency Measurements (revised second edition), by August Hund, McGraw-Hill Book Co., Inc., New York, 1951, xi + 676 pages, $10. A book in the International Series in Pure and Applied Physics.

Perturbation Methods in the Quantum Mechanics of *n*-Electron Systems, by E. M. Corson, Hafner Publishing Company, New York, 1951, xi + 308 pages, $11.

The New Physics, by Sir C. V. Raman, The Philosophical Library, Inc., New York, 1951, 144 pages, $3.75. This book, intended for the layman, contains a series of radio talks to the Indian public by India's most distinguished physicist and Nobel Prize winner. It carries an introduction by Francis Low of the Institute for Advanced Study at Princeton, N. J.

OTHER LITERATURE

Engineering New Fields. An 18-page booklet put out by The Kellex Corporation to describe its facilities and its work for the Atomic Energy Commission and the Armed Services. The company recently organized a department to study industrial applications of resulting new techniques and equipment. *Available without cost from The Kellex Corporation, 233 Broadway, New York 7, New York.*

A Guide for Contracting of Construction and Related Engineering Services. This is a revised edition of the Atomic Energy Commission's booklet describing how to do business with the AEC first published in October, 1949. *Available from Superintendent of Documents, United States Govt. Printing Office, Washington 25, D. C., $0.15.*

Industrial Health Monthly. This is the new name for the monthly journal published for some ten years under title "Industrial Hygiene Newsletter." Purpose and policies of the publication remain the same. It is published by the Federal Security Agency, Public Health Service, Washington 25, D. C., available at $1 per year from the U. S. Govt. Printing Office.

Soviet Atomic Espionage. A 222-page report published by the Joint Committee on Atomic Energy (GPO 81095, Joint Committee Print, 82d Congress, 1st Session). Voluminously documented, it contains all the salient facts about the individuals whose names have been publicly associated with atomic espionage. *Available without cost from the Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C.*

Laboratory Design, edited by H. S. Coleman. A 404-page treatise based on a National Research Council report on design, construction and equipment of laboratories. Handsomely illustrated, it contains information on every type of teaching and industrial laboratory. Myron B. Hawkins of the U. S. Naval Radiological Defense Laboratory has contributed a chapter entitled "The Design of Laboratories for the Safe Handling of Radioisotopes." *Reinhold Publishing Corporation, New York 18, New York, $12.*

CROSS SECTIONS

Tracer Method for Evaluating Rust Preventatives*

By Stanley L. Eisler
Chemist, Ordnance Corps, Rock Island Arsenal
Rock Island, Illinois

Tracer techniques applied to the testing of soft-film rust preventatives have overcome the shortcomings of testing procedures used to evaluate these compounds during U. S. Army procurement. The old test is based on visual identification of rust on steel test panels that have been dipped in water and then immersed in the preventative. Surface films, stains, drainage marks and mottled patterns often mask results, making it impossible to rate the rust preventative even on the "fail-pass" basis presented in U. S. Army Tentative Specification AXS-1759.

Comparison of the relative efficiencies of compounds rated as acceptable with the old test is possible with the tracer method. Step-by-step procedures for both the visual and radioactive tests are given on the next page. The tracer technique was kept similar to the visual one so that intercomparison would be easy.

Development of Tracer Test

The tracer method is based on the assumption that an isotope added to the water used to wet the test panels would be removed if all traces of the water were removed. If removal was incomplete, the residual radioactivity would be proportional to the amount of water remaining. Thus the counting rate obtained with the panel would be inversely proportional to the efficiency of the preventative.

Isotope used. Radiosulfur had been obtained from Oak Ridge National Laboratory in the form of dilute $H_2S^{35}O_4$ for use in another experiment. It was used in this investigation because it was on hand.

The labeled sulfuric acid was neutralized with (N/100) NaOH to form $Na_2S^{35}O_4$. This was added to the water used for wetting the test panels. Preliminary experiments resulted in the selection of an activity level of 0.5 μc per milliliter of water. A residual activity of about 40 times normal background was obtained from a test panel that was dipped in the labeled water, drained, immersed in a paraffin oil (assumed to have no water displacing properties), degreased and counted. This count-to-background ratio makes possible a large differential between compounds with poor and good water displacing properties.

Water application. Variations noted in preliminary tests indicated that drainage from the test panels after being dipped in water was not consistent. An alternative method for wetting the test panel was investigated. One drop of the water solution was allowed to fall on the panel from a height of 10 in. Held horizontally, the panel was then immersed in the com-

* The opinions or assertions contained in this article are not to be construed as official or reflecting the views of the Department of the Army.

Procedures for Testing Rust Preventative Compounds

U. S. Army tentative specification AXS-1759 (modified)	*Proposed supplementary radioactive tracer test*
1. Open-hearth low-carbon steel test panels ($2 \times 3 \times \frac{1}{16}$ in.) are sandblasted and thoroughly cleaned.	
2. Panels are momentarily dipped in a beaker of water.	2. Panels are momentarily dipped in beaker of water containing 0.5 μc of $Na_2S^{35}O_4$ per ml.
3. Panels are allowed to drain for 5 sec in a vertical position with bottom edge resting on absorbent tissue.	
4. Immediately after draining, the panels are immersed horizontally for 15 sec in a Petri dish containing 50 ml of the rust preventative compound being tested.	
5. Panels are then exposed for 1 hr in a 100% static humidity chamber maintained at 77° F.	5. Panels are then hung in a trichloroethylene degreaser for 15 min.
6. Panel is removed from chamber and cleaned.	6. Panel is removed from degreaser and dessicated until cool.
7. Visual inspection of panel for rust is made.	7. Centered on aluminum plate 10 mm from end-window G-M tube, panel is counted for 5 min and counting rate determined.

pound being tested, removed, degreased and counted.

Results indicated that the standard deviation for both methods of wetting was approximately the same. The immersion method provided a greater differential between the counting rates of good and poor water-displacing materials. These results, coupled with the desire to keep the tracer method consistent with the specification test, led to retention of the immersion method of wetting, even though there was a variation in water retention.

Compound application. The 15-sec immersion of the test panels in a Petri dish containing 50 ml of the rust preventative under test was retained from the specification test.

Degreasing. Varying thicknesses of films formed by different preventatives decreases accuracy of measurements since these films absorb part of the beta radiation from S^{35}. It is, therefore, necessary to remove these films before counting.

Several removal methods were tried. Spraying and slushing of the test panels with naptha or petroleum ether was difficult to perform in a reproducible fashion. Hot naptha slushing removed some of the radioactive water by evaporation, and petroleum ether slushing did not effect complete removal.

As a matter of convenience and efficiency, it was decided to standardize on vapor degreasing in a trichloroethylene vapor degreaser. Tests indicated that a 15 min degreasing time removed the oil residues effectively.

Counting. For counting, the steel test panel was centered on an aluminum plate placed on the first shelf of a Lucite mount. The surface of the panel was 10 mm from the 1.7 mg/cm² mica window of a Tracerlab TGC-2 counter;

this tube was operated at 1,350 volts.

The entire assembly was mounted in a vertical lead shield 1½ in. thick. Sample counts were made for 5 min; background counts, for 15 min or longer.

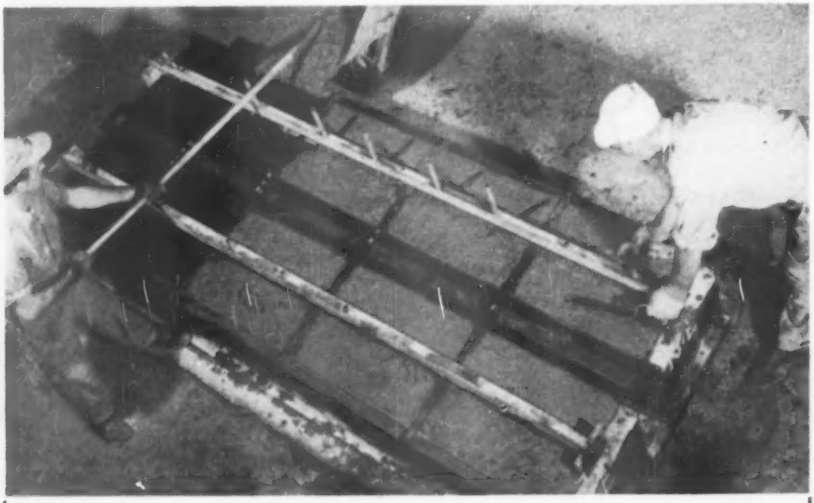
Comparison of Methods

To compare the new tracer method with the modified specification test, 14 commercial rust preventatives with varying water displacing efficiencies, plus paraffin oil as a negative control, were tested by both methods. The procedures used are given on page 77. The results are given in the table on the next page.

In general, if the net counting rate of a water displacing material is less than 25% of the net counting rate of the paraffin oil control, the material will pass the modified specification test. Note the counting rates of compounds *B*, *C*, *F*, *G*, and *K*.

Except for compounds *A*, *K*, and *M*, the counting rates in the table are averages for three test panels. For compounds *A* and *K*, one determination deviated so far from the mean that it was classed as a suspected determination and omitted. Compound *M* concentrated the water in droplets on one test panel, giving a counting rate of 1,198 cpm. This was omitted from calculations; only the counting rates of the other two panels—550 and 615 cpm—were used.

Compound *D* was not completely removed by degreasing; streaks were visi-



THESE FORMS are used by The Austin Company at Argonne National Laboratory for fabrication of the concrete shield blocks shown on the cover. The forms were made entirely from steel plates and angles which were welded together and milled to a tolerance of $\frac{1}{16}$ in. The blocks are 18 in. square and vary in length. Steel rods bent into triangular form are cast in each block to form lifting rings. Horizontal and vertical sleeves are provided for tubing and instruments within the finished blocks.

ble on two panels when counted. The streaked panels gave counting rates of 341 and 426 cpm; an apparently clean panel gave 147 cpm. It is safe to assume that this compound would give a counting rate less than 25% of that for paraffin oil if all of it were removed.

A considerable variance between the counting rates of individual panels is indicated by the standard deviations given in the table, especially when there is limited or no displacement of the water. While this variation can be attributed to a number of sources of error, it does not prevent evaluation of the relative efficiencies of rust preventatives. It is noteworthy that the superiority of compounds *B* and *G*, as shown by the tracer method, could not be ascertained by the visual specification test.

The tracer method for testing rust preventatives is not expected to replace the specification test because many suppliers do not possess the required equipment. It should, however, prove valuable as a supplementary test.

Comparison of Tests

Compound	*Average cpm (net)*	*Standard deviation*	*Result of modified test*
A	767	15	Fail
B	38	2	Pass
C	234	30	Pass
D	374	22	Pass
E	563	45	Fail
F	213	41	Pass
G	50	4	Pass
H	537	48	Fail
I	514	13	Fail
J	566	145	Fail
K	210	2.5	Pass
L	1,088	69	Fail
M	559	32	Fail
N	820	72	Fail
Paraffin oil	988	98	Fail

The author thanks his coworkers at Rock Island Arsenal Laboratory for their assistance, and appreciates the permission of the Ordnance Corps, Research and Development Division of the Department of the Army, and the Laboratory's supervisory staff to publish the information in this paper.

Dry Box Design Provides Ease in Manipulation

By Louis G. Stang, Jr.
Hot Laboratory Operations Group
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Designed primarily for delicate physical manipulations, a plywood dry box has gloves for the manipulator's hands located so as to eliminate the cramping encountered with conventional boxes. The box is small and compact—20 in. square—and can be placed on a low table in front of the operator. The top slopes to provide good visibility of the interior of the box.

Three shelves are provided in the

(Continued on page 92)

Plywood dry box

NUCLEONIC EVENTS

RECORD BUDGET ASKED FOR AEC OPERATIONS IN 1952

The $1,210,000,000 budget requested by the Atomic Energy Commission for the fiscal year 1952, the fifth annual budget, is by far the largest annual budget the Commission has ever presented to the Congress. It represents a larger percentage for operations and a smaller percentage for plant and equipment than previous budgets. The explanation given by the chairman of the Commission, Gordon Dean, is that during fiscal year 1951, Congress voted $1,431,000,000 for plant and equipment alone, largely in supplemental appropriations, which was used for extension of the reactor program at Savannah River and the gaseous diffusion plant at Paducah.

The large operation figure of $580-million ($511-million accrued costs plus $69-million for inventories and other obligations) is attributed to the fact that the additions to AEC plant provided for in previous years will begin to require operating money in 1952.

Accrued costs for operations and plant and equipment for the fiscal years 1950–52 are tabulated below.

Estimates in the budget are based on price and wage levels prevailing as of July 1, 1950, it was explained, and therefore may require extra appropriations to carry out the program outlined. Additional amounts will be requested for the Savannah River con-

Accrued Costs by Activities—U. S. Atomic Energy Commission

Description	*Actual, fiscal year 1950*	*Estimate, fiscal year 1951*	*Estimate, fiscal year 1952*
Operations (accrued cost basis):			
Source and fissionable materials	$120,416,680	$148,423,800	$209,738,000
Weapons	85,832,512	135,487,771	161,134,000
Reactor development	27,596,200	39,060,426	51,435,000
Physical research	31,128,252	33,610,200	37,766,000
Biology and medicine	17,687,416	22,116,623	22,412,000
Community management	5,805,387	5,014,317	3,311,000
Program direction and administration	22,092,169	24,552,751	25,944,000
Total operating costs	$310,558,616	$408,265,888	$511,740,000
Plant and equipment (accrued cost basis):			
Source and fissionable materials facilities	$ 68,275,992	$198,468,230	$537,256,000
Weapons facilities	79,047,601	70,538,000	115,000,000
Reactor development facilities	36,534,734	48,450,094	50,000,000
Physical research facilities	22,712,375	30,669,365	37,370,000
Biology and medicine facilities	5,028,878	9,163,815	6,333,000
Community facilities	43,325,629	33,486,462	10,120,000
Administrative facilities	1,200,522	497,158	278,000
Total plant and equipment costs	$256,125,731	$391,273,124	$756,357,000

struction project. By midsummer estimates of cost will be presented to the Commission by the contractor, the duPont Company.

$51,300,000 MORE SOUGHT FOR AEC THIS YEAR

Last month President Truman asked Congress for an additional $51,300,000 for "urgent production and research facilities" for the Atomic Energy Commission. The money, the President pointed out, is needed in this fiscal year which ends June 30. He gave no details on how the sum was to be used.

METALLURGICAL ADVISORY BOARD IS ORGANIZED

Announcement was made recently of formation of a board of leading industrial and academic metallurgists to advise the Department of Defense on research aspects of some of the nation's most critical metals problems. Dr. Robert F. Mehl, head of the department of metallurgy at Carnegie Institute of Technology, is chairman of the Board.

Among the metals in critically short supply listed tentatively for the Board's study are columbium, tantalum, cobalt, titanium, molybdenum, tungsten, and beryllium.

The Board was organized by the National Academy of Sciences–National Research Council under a contract with the Research and Development Board.

MICHIGAN'S PHOENIX PROJECT ANNOUNCES NEW GRANTS

Thirteen new investigations into the peaceful uses of atomic energy have been started as a result of funds in the amount of $25,000 made available by the Michigan Memorial–Phoenix Project at the University of Michigan.

Among the physical investigations to be started are researches to determine how fast gases intermingle at high pressure, experiments in polarized X-rays, and a study of high-energy particles in biophysics. Radiochemical analysis and nuclear chemical separations will be carried out as part of the chemical investigations authorized.

Another investigation made possible by the grants went to the university's medical school. ACTH will be compounded with radioiodine to make blood-pressure studies.

The metabolism of tagged amino acids by frog embryos is one of the researches to be made in zoology, as is an investigation into the processes involved in the formation of the color pigment in human hair. The course of migration of lungworms in deer will also be studied.

The Botany Department has received grants to investigate dating of human and vegetational remains in the Aleutians by the carbon-14 method and to attempt artificial development of egg cells in certain plants without fertilization.

How radiation affects the metabolism of proteins, carbohydrates, fats, and vitamins in bacteria is the subject of another investigation.

ISOTOPES IN INDUSTRY DISCUSSED AT TWO CONFERENCES

"Radioisotopes in Industry" was the subject of conferences held recently by the Case Institute of Technology and Iowa State College.

Taking place April 2–6 in Cleveland, Ohio, the Case conference program included the following technical subjects and speakers: *Introduction to Nuclear Theory*, R. S. Shankland; *Nuclear Reactions*, J. R. Bradford; *Atomic Energy—Uses and Benefits*, Paul C. Aebersold; *Radioisotope Production and Separation*, A. F. Rupp; *Measurement and Characterization of Radiation*, E. F. Shrader; *Interaction of Radiation with Matter*, E. C. Gregg, Jr.; *Biological Effects of Radiation* and *Medical Uses of Radioisotopes*, Hymer L. Friedell; *Radiation Protection*, Otto Glasser; *Radioisotopes*

in Physical and Chemical Research, G. D. Calkins; *Planning a Tracer Experiment* and *Pitfalls of a Tracer Experiment*, Rex Fluharty; *Radioisotopes in Industry*, Charles Rosenblum; *Typical Radiochemical Laboratories*, Tom B. Lanahan; *Instrument Problems of the Radiochemical Laboratory*, V. L. Parsegian; *The Atomic Energy Commission and Industry*, T. Keith Glennan; *Decontamination and Waste Disposal*, C. C. Ruchhoft; *Industrial and Safety Problems Associated with Radioisotopes*, Reuel Stratton; *The Isotope Distribution Program*, N. H. Woodruff; *Uses of Gross Fission Products*, P. J. Lovewell, Paul M. Cook, and William E. Hosken.

The Iowa State College conference was held at Ames on May 1–3. Divided into four sessions, it included an introduction to the subject of isotopes by F. H. Spedding, director of the college's Institute for Atomic Research. The following topics were discussed by other IAR staff members: *Atoms, Isotopes, and Radioactivity; Instrumentation for a Tracer Laboratory; Planning a Tracer Experiment; Health and Safety Precautions;* and *Design of Research Facilities.* Radiation equipment was demonstrated, and J. R. Mason of the AEC's Isotopes Division spoke on *The AEC and Industry.*

BOARD OF SCIENTISTS NAMED TO SELECT AEC FELLOWS

A nine-man board to select Atomic Energy Commission fellows for the 1951–52 school year has been announced by the Oak Ridge Institute of Nuclear Studies, administrator of AEC fellowships. The president of the board is George B. Pegram (Columbia University). Other members are: George H. Boyd (University of Georgia), Robert G. Brode (University of California), Detlev W. Bronk (Johns Hopkins University), Leland J. Haworth (Brookhaven National Laboratory), Warren C. Johnson (University of Chicago), Homer W. Smith (New York University School of Medicine), Elvin C. Stakman (University of Minnesota), and Douglas Whitaker (Stanford University).

The board will meet at Oak Ridge in the near future to make a final selection of fellows. Preliminary selection is now being made by the fellowship boards of the National Research Council.

STUDY BEGUN ON HEALTH OF URANIUM MINE WORKERS

A mobile force of eight U. S. Public Health Service researchers will take the field in early June in the Colorado plateau region to study possible health hazards encountered in the uranium mining operations of Colorado, Arizona, Utah and New Mexico. Similar field work was done last summer in mills at Durango, Naturita, and Uravan, Colorado, and Monticello, Utah.

The research program, carried out with federal, state and National Cancer Institute funds, is headquartered at the USPHS Division of Industrial Hygiene Field Station on the University of Utah campus in Salt Lake City.

A complete report will not be available on the study until late 1952 or early in 1953. Information that uranium miners in Czechoslovakia and Eastern Germany have suffered severely from uncontrolled exposure to ionizing radiations and the effects of radon gas (some statistics indicating a lung cancer mortality of 44% in mines and mills behind the Iron Curtain) have spurred early completion of the study.

No American miners have as yet been found to show signs of illness resulting from high exposure. However, indications of lung cancer are usually not apparent until workers have been exposed to a considerable degree of radiation sometimes for as much as ten years.

The complexity and thoroughness of the task to be undertaken is indicated by the fact that urine-uranium analyses of the men involved are run at laboratories of the AEC at Los Alamos; U. S. Navy facilities in Maryland are handling the radon gas tests, while both the University of Rochester and the University of Utah are making laboratory studies on the toxicology of uranium-bearing ores.

X-rays of some 700 mill workers and controls were taken last year, and at least an equal number of underground miners will have their health and working conditions thoroughly checked during this season's field work.

BENDIX MAY STUDY FEASIBILITY OF BUILDING ISOTOPE REACTOR

The Bendix Aviation Corporation, Detroit, Mich., has started discussions with the Atomic Energy Commission on a Bendix proposal to undertake a privately financed feasibility study of a nuclear reactor to produce radioisotopes on a commercial basis. It is expected that working arrangements for this study will be similar to those set up with the Monsanto Chemical Company and jointly with the Detroit Edison Company and the Dow Chemical Company (NU, Feb. '51, p. 86) for their power-reactor feasibility investigations. These arrangements provide that a limited number of "properly qualified and cleared persons" will have access to existing information and will be permitted to take up a "reasonable share of the time of Commission personnel."

OHIO TO BE SITE OF AEC FEED MATERIALS PLANT

A uranium-ore refinery and other facilities for the production of uranium feed materials will be constructed by the Atomic Energy Commission on a 1,200-acre site on the Miami River about 19 miles northwest of Cincinnati, Ohio. About 1,200 persons will be required to staff the $30-million installation.

The George A. Fuller Company of New York City has been awarded the construction contract. Designing is being done by the Catalytic Construction Company of Philadelphia. The site will be known as the Fernald Area, and it will be administered by the New York Operations Office of the Atomic Energy Commission.

NBS TO OPERATE NEW LAB IN COLORADO FOR AEC

The National Bureau of Standards will operate a specialized research laboratory which the Atomic Energy Commission last month announced would be built on a section of the NBS grounds south of Boulder, Colorado. An operating staff of about 50 persons will be employed, many of whom will be scientists and specialized technicians. The nature of the operations to be carried out at the laboratory was not disclosed.

The AEC has contracted with Stearn-Rogers of Denver, Colo., for architect-engineer services.

MIT TO OFFER FORMAL PROGRAM IN NUCLEAR ENGINEERING

With the recent appointment of Dr. Manson Benedict as professor of nuclear engineering at Massachusetts Institute of Technology, plans were revealed to organize a formal program of education in nuclear engineering at the Institute. At the start, a degree in nuclear engineering will be offered at the graduate level.

Dr. Benedict who will join the MIT staff on July 1, will also, it was recently

announced, serve as scientific director of the National Research Corporation.

INDIA PLANS REACTOR FOR EXPERIMENTAL PURPOSES

The Indian Atomic Energy Commission recently made known its plans to construct a small nuclear reactor to be used for research and the production of radioisotopes.

The announcement was made to the Indian Parliament by Sri Prakasa, Minister for National Resources and Scientific Development, who reviewed the work of the Commission and told of the progress being made toward completing construction of a plant in southwest India capable of processing 1,500 tons of monazite annually.

28 NEW RESEARCH CONTRACTS AWARDED BY AEC

During the first two months of this year, the Atomic Energy Commission awarded a total of 28 new unclassified research contracts to the institutions which, together with the names of the investigators and the subject of the research, are listed below:

In Physics

University of Connecticut (S. Friedland)
Mass Spectrographic Analysis of Geiger Counter Cases

Alabama Polytechnic Institute (Howard Carr)
Research with Mass Spectrometer

New York University (M. H. Shamos)
Cosmic-ray Research

University of North Carolina (Everett Palmatier)
Absolute Intensities of Cosmic Radiation

Columbia University (C. H. Townes)
Determination of Nuclear Moments and Masses by Microwave Spectroscopy

University of Michigan (H. R. Crane)
500-Mev Racetrack Synchrotron

Ohio State University (J. N. Cooper)
Research with Van de Graaff Generator

Oregon State College (W. A. Yunker)
Construction of 52-inch Cyclotron

State College of Washington (R. M. Brown)
Nuclear Magnetic Resonance in Liquid Solutions

Rensselaer Polytechnic Institute (D. C. Moore and G. N. Glasoe)
Development and Use of High-speed Coincidence Circuits; also *Development and Application of Techniques in the Field of Beta-ray Spectroscopy*

In Chemistry

Catholic University of America (Gilbert W. Castellan)
Electrical Effects of Phase Boundaries

Catholic University of America (Walter J. Moore)
Rate Processes in Inorganic Compounds at High Temperatures

Michigan State College (M. T. Rogers)
A Physico-chemical Investigation of Interhalogen Compounds

Oklahoma A & M College (T. E. Moore)
Separation of Inorganic Salts by Liquid-liquid extraction

Oregon State College (A. V. Logan)
A Study of the Mechanism of the Jacobsen Rearrangement

Vanderbilt University (E. A. Jones)
Raman Spectra of Some Inorganic Compounds

In Metallurgy

Armour Research Foundation (Max Hansen)
Phase Diagram of Zirconium-base Binary Alloys

Rensselaer Polytechnic Institute (H. B Huntington)
Anisotropic Self-diffusion in Metals

In Biology and Medicine

State College of Washington (C. O. Stanberry)
Zinc Nutrition of Plants in Calcareous Soils

Yale University (John H. Heller)
Factors Influencing Tissue Sensitivity to Radiation; also *Related Study of Oxidative and Reductive Factors in Relation to Radiation Cataracts*

University of Cincinnati (Robert A. Kehoe)
Biological Effects of Beryllium and Its Compounds

Michigan State College (H. B. Tukey)
Absorption and Utilization of Radionuclides Applied to the Leaves of Plants

University of Virginia (A. Chanutin)
Effect of Ionizing Irradiation on Mammals

Tulane University (W. S. Wilde)
Exchange Rate of Tissue Electrolytes

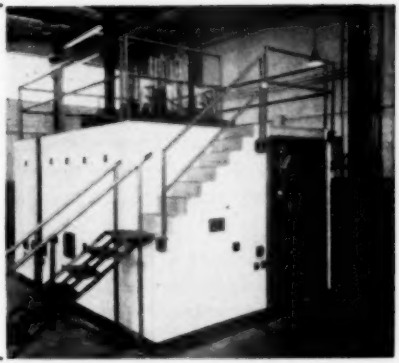
Louisiana State University and A & M College (John F. Christman)
Effect of Biotin on Acetate Utilization and Lipide Synthesis by Microorganisms

University of North Carolina (Maurice Whittinghill)
Partial Elimination of Lethal Genes Before Reproduction in Drosophila by the Use of Environmental Agents

Washington University, St. Louis, Mo. (Wendell G. Scott)
Scanning of In-Vivo Concentrations of Radio-

CLEMENTINE . . .

. . . is the fast reactor at Los Alamos Scientific Laboratory in New Mexico. Fast neutrons produced by the fission of plutonium sustain the chain reaction. Liquid mercury is used as the coolant. This is the only such reactor in operation. Since this photo was taken, the control mechanism on top of the reactor has been modified.



activity in an Attempt to Locate Metastatic Tumors and Internal Malignancies in the Human Body

Washington University, St. Louis, Mo. (Michel Ter-Pogossian)

Measurement of Clinical X-ray Dosages and Intensities by Means of the Use of Scintillation Media

The new awards bring to 371 the number of unclassified research projects (222 in biology and medicine and 149 in physical research) being supported by the AEC in hospitals, educational institutions, and industrial organizations. In addition, the AEC supports 73 unclassified projects jointly with the Office of Naval Research.

MARCH ISOTOPES SHIPMENTS SET NEW RECORD

A total of 857 radioisotopes shipments dispatched by the AEC's Isotopes Division in March, 1951, established a record as the highest monthly shipment since the first shipment was made on August 2, 1946. Shipments to date have almost reached the 23,000 mark. Industry's demand for cobalt in 1950 brought that year's shipments to 8,075.

AEC PLANS PRODUCTION PLANT IN COLORADO

The AEC has announced that a new production plant, for a secret type of operation, will be built on a four-square-mile site near Denver, Colorado. The Santa Fe Operations Office of the AEC, responsible for research, development, production, and testing of atomic weapons, will administer the $45-million facility. When full operations commence, 1,000 persons will be employed.

Plant operation will be by the Dow Chemical Company, Midland, Michigan. Designs will be made and construction supervised by the Austin Company of Cleveland, Ohio.

IN BRIEF

➤**$1,000,000** is being distributed equally among Columbia, Harvard, Princeton, and Yale by the Eugene Higgins Scientific Trust. Columbia will use its share of the fund to continue its research in nuclear, atomic, and molecular physics.

➤***Animals** will be exposed to radioactive dusts under conditions similar to those found in uranium mining operations as part of a new cancer research project to be carried out at the University of Utah. A Public Health Service cancer control grant of $19,602 was made for the work.*

➤**Atomic blast effects** on structures and materials of various kinds will be studied as part of the weapons tests

taking place this month at the Eniwetok Proving Ground in the Pacific. With instrumentation specifically arranged to provide information useful for developing design criteria for architects, the AEC is carrying out a major project to supplement data already obtained from other atomic blasts.

➤***Injury rate*** *in the atomic energy program in 1950 showed a 22% reduction compared to the 1949 figure. An average of 4.67 employees were injured for every million man-hours worked in 1950. The most recently reported average for all U.S. industry was 10.14.*

➤**Contractor** for the new AEC developmental facility to be built in Missouri on the site of the Weldon Spring Ordnance Works is the California Research and Development Company of San Francisco. A subsidiary of the Standard Oil Company of California, it has been named architect-engineer-management contractor for the facility.

➤***Geneticists*** *at the University of Michigan are launching a new heredity study under AEC sponsorship. Certain inherited diseases of the kidneys, large intestine, nervous system, and blood will be studied in an attempt to estimate how frequently the spontaneous genetic changes take place that produce the diseases. Funds of $21,060 have been provided for the first year's work on the project.*

➤**Shots** of AEC installations and laboratories are being filmed by the Signal Corps for eventual use as documentary footage by private motion picture companies.

NUCLEAR NEWSMAKERS

James Bryant Conant, president of Harvard University, will serve as honorary president of the Twelfth International Congress of Pure and Applied Chemistry, to be held in New York, September 9–13.

G. Victor Beard has been named to head the health physics branch of the AEC's Idaho Operations Office. He was formerly professor of physical chemistry at the University of Utah.

G. O. Haglund, formerly manager of the Engineering Physics Division of Frederick Flader, Inc., has been named assistant director of General Mills Aeronautical Research Laboratories in Minneapolis. He was formerly active in research and development work for the AEC and U. S. Air Force.

Wells R. Dickinson has been named resident engineer for the AEC's chemical processing plant in Idaho. **Herbert M. Leppich** has been appointed project engineer for construction of the plant.

Werner Heisenberg, German atomic scientist, is planning to visit Argentina on a lecture tour next fall.

Alan Gregg, chairman of the AEC's Advisory Committee for Biology and Medicine, has been named vice president of the Rockefeller Foundation. He served the Foundation for twenty years as its director for the medical sciences.

Sir John Douglas Cockcroft, director of the Atomic Energy Establishment at Harwell, England, and **Niels Bohr,** professor of theoretical physics, Copenhagen University, will receive honorary degrees at Glasgow University in June during the celebrations which will be held to mark its 500th anniversary.

Andrew Kalitinsky, who joined The M. W. Kellogg Company following his resignation as chief engineer of the NEPA Project at Oak Ridge, has been named manager of the company's Special Projects Department which is doing research and development work on rockets and rocket motors for the U. S. Air Force and Navy.

William F. Giauque of the University of California has been named by the

Chicago Section of the American Chemical Society to receive the Willard Gibbs Medal for 1951. He is credited with discovering the oxygen isotopes 17 and 18, and was awarded the Nobel Prize in Chemistry in 1949 for his low-temperature research.

Robert G. Miller, formerly vice president and general manager of Tracerlab, Inc., has been elected president of Kelley-Koett Manufacturing Company. He will continue to hold a vice presidency with Tracerlab, which recently purchased a majority interest in Kelley-Koett. Additional changes in Tracerlab's management include the promotion of **Sidney S. Minault** to vice president and general manager of Tracerlab and **William A. Kerr** to vice president.

Roger I. Harris has received appointment as Deputy General Counsel of the Atomic Energy Commission. Mr. Harris, one of two AEC deputy general counsels, succeeds Bennett Boskey who resigned to engage in private law practice.

Lyle B. Borst, chairman of the Department of Reactor Science at Brookhaven National Laboratory, has been elected chairman of the Federation of American Scientists for 1951–52. He succeeds **W. A. Higinbotham,** also of Brookhaven, who was chosen vice chairman.

Virginia C. Duncombe has been appointed assistant general counsel in charge of legal work at the AEC's New York Operations Office. Mrs. Duncombe replaces **Edward Diamond,** assistant general counsel in New York since 1947, who will assume the same post at the Commission's Berkeley, California, Office.

Norris E. Bradbury, director of Los Alamos Scientific Laboratory, **Donald W. Kerst,** professor of physics at the University of Illinois, **E. M. Purcell,** professor of physics at Harvard University, and **Frederick Seitz,** research professor of physics at the University of Illinois, are among the twenty-nine scientists recently elected to the National Academy of Sciences.

Kenneth S. Pitzer, director of the AEC's Division of Research, has received the "Alumnus of the Year" award from University of California alumni for his outstanding achievements in 1950.

Charles A. Thomas, key figure in the development of atomic energy, became president of Monsanto Chemical Company on May 1. Formerly executive vice president, he succeeds **William McNear Rand.**

NECROLOGY

Robert Burbidge Taft (April 16, 1951). Member of the board of medical consultants of the Oak Ridge Institute of Nuclear Studies, Dr. Taft died of cancer at the age of 55 in Charleston, S. C. He was the author of numerous monographs and books on radium and X-rays, and is credited with developing the radium electroscope. The American Roentgen Ray Society honored him in 1936 and 1942 with its silver medal award for his work in radioactivity. He had been professor of radiology since 1924 at the Medical College of South Carolina.

MEETINGS

American Society of Mechanical Engineers, Nuclear Energy Division of Metropolitan Section (field trip to Brookhaven National Laboratory)—Upton, N. Y., May 19

American Society of Mechanical Engineers, Semiannual Meeting—Royal York Hotel, Toronto, Canada, June 11–15

Symposium on Analysis and Metallography of Titanium (sponsored by Armour Research Foundation of Illinois Institute of Technology)—Sheraton Hotel, Chicago, Ill., June 11–13

1st National Congress of Applied Mechanics—Illinois Institute of Technology, Chicago, Ill., June 11–16

(Continued on page 92)

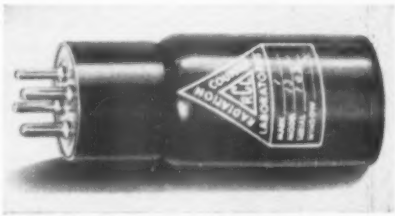
PRODUCTS and MATERIALS

VARIABLE SCALE

Gerber Scientific Instrument Co., 89 Spruce St., Hartford, Conn. Any number of divisions per inch can be set on the triangular spring of the Gerber variable scale. This spring has 100 divisions; when compressed it is 1 in. long and when fully extended is 10 in. long. Problems involving spacing, scaling, proportions, graphical-algebraic calculations, plotting, etc. can be solved immediately. For instance, graphical interpolation is accomplished by setting the scale, laying it along the graph, and reading the answer.

HAND AND FOOT MONITOR

General Electric Co., Electronics Park, Syracuse, N. Y. The model 4SN12A1 hand and foot monitor is designed for doorway use in areas where personnel work with radioactive materials. Twelve beta-gamma tubes are used; two for each hand surface and four for the feet. The pulses from the G-M tubes are scaled down and totalized on five registers. The instrument draws 480 watts at 105–130 volts, single phase, 50–60 cycles. An overload relay protects the G-M tubes from excessive voltages. Monitor and controls are mounted in separate cabinets.



BISMUTH-CATHODE COUNTER

Radiation Counter Laboratories, Inc., 1844 W. 21st St., Chicago 8, Ill. The mark 1, model 13, is a G-M counter with glass wall and bismuth screen cathode. In counting the gammas from I^{131} it is said to be more than 7 times as efficient as similar shaped mica-window counters. For operation at about 1,050 volts, a plateau length of 150–200 volts and a life of 10^8 counts are claimed.

POWER SUPPLY

Kepco Laboratories, Inc., 149–14 41st Ave., Flushing, N. Y. The model 815 combines three power supplies in a single cabinet. The B supply is continuously variable from 0–600 volts and delivers from 0–200 ma; the C

supply is continuously variable from 0–150 volts with a load of 5 ma. Both are regulated to within 0.5% for line fluctuations from 105–125 volts and load variations from minimum to maximum. Ripple in both cases is less than 5 mv. The a-c filament supply delivers 10 amperes at 6.3 volts, unregulated.

VACUUM PUMP

Kinney Mfg. Co., 3529 Washington St., Boston 30, Mass. Employing an oil-sealed system, the model CVM 3153 compound pump is said to have a free air displacement of 2 ft^3/min and to reach McLeod gage readings of 0.1 μ. It is also supposed to retain a high percentage of its volumetric efficiency in the low pressure regions. The unit has been designed for portability; weight is 70 lbs, size about 1 ft on a side.

CANADIAN CONSULTANTS

Isotope Products, Ltd., 8th Line, Oakville, Ontario (P. O. Box 127) has been formed by N. Z. Alcock, D. C. Brunton, and R. F. Maskell, formerly of the Chalk River Atomic Energy Project, and P. J. Stewart, formerly of the Harwell Atomic Energy Project. This is the first Canadian consulting and engineering firm in the field of radioactivity.

BETA-RAY GAGE

Industrial Nucleonics Corp., 1205 Chesapeake Ave., Columbus 12, O. Variations in weight per unit area of moving sheet materials are continuously recorded by measuring beta-ray absorption. Using a strontium-90 source and an ionization-chamber detector, this instrument can measure thicknesses up to about 600 mg/cm^2. It is said that variations as small as 10^{-5} in. can be detected. The instrument is designed to withstand severe shocks and adverse conditions of all sorts. Rigid H-beam construction keeps the source-detector distance constant. Industrial tubes are used in the electronic circuits to minimize damage and increase lifetime. Several sizes of source-detector mounts are available, the largest permitting measurements to be made up to 4 ft in from the edge. Operation is completely automatic, including calibration at regular intervals. Provision is made for scanning across the sheet and for spot checking at selected locations.

MICROPHOTOMETER

American Instrument Co., Inc., Silver Spring, Md. This photomultiplier microphotometer will measure and compare light intensities from 20 $\mu\mu$lumens to 20 lumens at selected wavelengths. Among its uses are film densitometry

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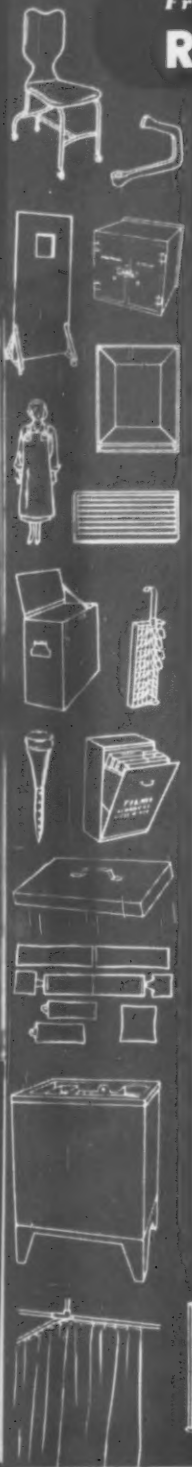
BAR-RAY

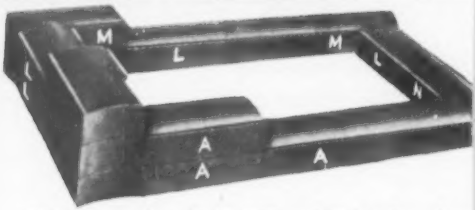


LEAD BRICK

1. No longer necessary, as with flattened brick, to lay an inner wall for blocking off joints in outer shield. One layer suffices!

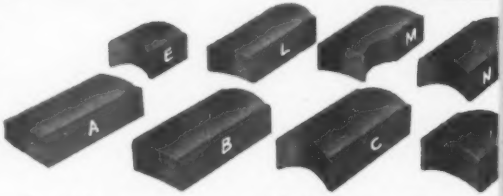
2. Compact stacking, due to convex tops and concave bottoms, and to narrow, flattened borders. "Socket-Fit" insures safe wall of any practicable height or length.

3. To meet all possible requirements, eight "shapes" are available in each of two sizes of bricks. Standard full size for 4" protection is 8" x 4"x2". The standard full size for 2" protection is 6" x 3" x 2".



Full rectangular shield, 12" x 24" interior, show no straight-line-of-break at vertical or horizontal joi

Minimum brick-shapes required to form (left) interior rectangle 12" x 12" (Shapes L and M) and (right) interior rectangle 20" (Shapes A, L and M).



Complete assortment of brick-shapes for 4" wall p tection. Shapes D and E are half-bricks, others full si

Shapes M, A and L of the 2" barrier thickness.

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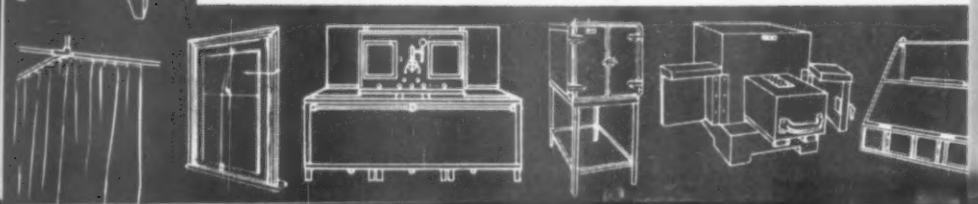


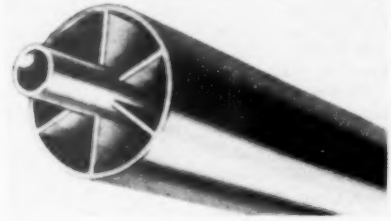
and measurement of scintillation efficiency of phosphors. Full-scale deflections of the meter are given with photomultiplier currents of 10, 1, 0.1, and 0.01 μa. Transmission, density, and current are indicated directly without correction factors. Currents as low as 10^{-11} amps can be read. Commercial recorders can be operated from a 10 mv, 100 μa, panel outlet.

VACUUM TEST CHAMBER

Tenney Engineering, Inc., 26 Avenue B, Newark 5, N. J. Performance of component parts at various altitudes or degrees of vacuum can be tested in this chamber. A pressure regulating valve enables the operator to select and hold any desired equivalent altitude up to 60,000 ft. The chamber is equipped with vacuum pump and direct-reading altitude gage.

RADIOCHEMICALS

Nuclear Instrument and Chemical Corp., 223 W. Erie St., Chicago 10, Ill. Biosynthesized glucose, sucrose, and fructose, tagged with C^{14}, are being produced. Other biosynthesized and some chemically synthesized radioactive carbon compounds will also be produced.



RADIAL-FIN TUBING

Modine Mfg. Co., Racine, Wis. This two-fluid-pass heat transfer surface has two concentric tubes and radial fins. The fin and tube elements are fusion bonded for maximum heat transfer. Available in a number of different metals it comes in lengths up to 20 ft. Connection to both passes is provided by T fittings, and arrangement in series-parallel banks can be made.

NEW FILTER COMPANY

Cambridge Corp., 350 South Geddes St., Syracuse, N. Y. has been formed by Arthur D. Little, Inc., 30 Memorial Dr., Cambridge 42, Mass. and the Carrier Corp., Syracuse, N. Y. The new company will produce a filter designed to keep radioactive particles out of the atmosphere. The filter, a soft feltlike paper containing submicroscopic asbestos fibers, is said to remove all but 1 in 20,000 particles from a cubic inch of air.

LITERATURE AVAILABLE

Monitoring. Booklet entitled "How Safe?" describes radiations and radiation hazards encountered in civil defense and industry. Monitoring equipment is recommended. *Tracerlab, Inc., 130 High St., Boston 10, Mass.*

Positive-Ion Accelerators. Bulletin H gives data on Van de Graaff accelerators for positive ions. *High Voltage Engineering Corp., 7 University Rd., Cambridge 38, Mass.*

Cleaning Equipment. Illustrated catalog lists machinery and equipment for cleaning small parts. *L & R Mfg. Co., 577 Elm St., Arlington, N. J.*

Spectrometer. Information on a direct-reading spectrometer is given in an illustrated brochure. *Applied Research Laboratories, 4336 San Fernando Rd., Glendale 4, Cal.*

Counter Tubes. Booklet contains data sheets for G-M tubes. Operating characteristics and physical dimensions are given. *20th Century Electronics, Ltd., Dunbar Works, Dunbar St., West Norwood, London, S. E. 27, England.*

rear corner, and the rack on the rear left wall in the illustration holds six test tubes. These can be used as holders for tweezers and small tongs.

The projection in the foreground is an air lock for introducing and withdrawing samples. The gloves used are the type used by veterinarians; their over-all length is 35 in.

A small inlet and exhaust tube can be added if it is desired to sweep out the air with an inert gas. The front half of the cover folds back or the entire cover can be removed for decontamination. Both the periphery of the cover and the diagonal joint at the hinge are gasketed with rubber to provide an airtight seal. The box is of simple plywood construction and may be considered expendable.

Discovery of Two New Artificial Elements Confirmed

Positive identification of two new artificial elements has been given by spectroscopic investigations at the National Bureau of Standards. They are elements number 43, known as technetium (Tc), and number 61, known as promethium (Pm). Not found in nature, they are byproducts of uranium fission; 6.2% of fission fragments are technetium and 2.6% are promethium. The most stable technetium isotope is that of mass 99, having a half-life of 5×10^5 y. The most stable promethium isotope has a mass of 147 and a half-life of 3.7 y.

TECHNICAL BRIEFS

→**One ton of sand** from certain California beaches will yield one pound of uranoan thorite, according to Dr. C. O. Hutton of Stanford University. Uranoan thorite contains 7% UO_2.

→***Mercury-198 lamps** are available to qualified laboratories from the National Bureau of Standards. These lamps are used as standards for precision measurement of length. Accuracy of one part per million is obtainable with them.*

Nucleonic Events (*Continued from page 87*)

American Physical Society—Schenectady, N. Y., June 14–16

American Chemical Society, Analytical Division—Washington, D. C., June 14–16

American Society for Testing Metals, 54th Annual Meeting—Chalfonte-Haddon Hall, Atlantic City, N. J., June 18–22

Symposium on Analysis and Metallography of Titanium (June 11–13); Symposium on Surfaces (June 14–16)—Illinois Institute of Technology, Chicago, Ill.

American Physical Society—Vancouver, B. C., June 25–28

American Institute of Electrical Engineers, Summer General Meeting—Royal York Hotel, Toronto, Canada, June 25–29

Congress on Nuclear Physics—Copenhagen, Denmark, July 6–10

Oak Ridge Summer Symposium (on Nuclear Engineering) sponsored by Oak Ridge National Laboratory and Oak Ridge Institute of Nuclear Studies—Oak Ridge, Tenn., Aug. 27–Sept. 6

American Chemical Society, Diamond Jubilee Meeting—New York, Sept. 3–7

American Mathematical Society, 472d Meeting—Minneapolis, Minn., Sept. 4–7

Twelfth International Congress of Pure and Applied Chemistry—New York, Sept. 10–14

Instrument Society of America, National Exhibit and Technical Meeting—Coliseum, Houston, Texas, Sept. 10–14

International Union of Chemistry, 16th Conference—New York, Sept. 8–9; Washington, D. C., Sept. 14–15

American Roentgen Ray Society—Shoreham Hotel, Washington, D. C., Sept. 25–28

American Society of Mechanical Engineers, Fall Meeting—Hotel Radisson, Minneapolis, Minn., Sept. 25–28

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readers' point of view) to discontinue abstracts and substitute one or two full-length articles.

We hope that the surveys we are presently conducting will justify our editorial scope as we have now defined it (see NU, Sept. '50, p. 2, for a detailed statement of our scope). With a field as broad as nucleonics, we have subscribers representing almost every conceivable profession. It is difficult to satisfy each reader in each issue of NUCLEONICS, but that is our goal.

We have a flexibility in determining the content of any issue of NUCLEONICS which most other scientific journal editors do not. This flexibility comes from the fact that we publish both review papers and original reports. Original reports are usually published in order of receipt. Review papers are generally written at the request of the editors to give NUCLEONICS the broad subject coverage necessary. These papers are frequently used to round out the contents of some particular issue.

• **Next month's issue** will contain a special section on "Practical Aspects of Radioactivity Instruments." This section will be divided into three parts: (1) Construction; (2) Testing and servicing; and (3) Calibration. The material will be subdivided according to types of instruments and circuits and according to type of radiation.

Publication of this section was arranged because of repeated requests we have received from readers. We believe that this will be the first collection of such information in one place.

• ***In a visit** we had last month with the vice president in charge of research of a large industrial firm active in the nucleonics field, we received the first really optimistic comment we have yet received on the potential growth of this field. This man, who is a reader of* Electronics, *used that magazine for describing the growth of nucleonics and NUCLEONICS. With his fingers, he indicated how much thicker than* Electronics *he thought NUCLEONICS would be in the future. For the record, the April issue of NUCLEONICS contained 104 pages and that of* Electronics *contained 344. And, again for the record,* Electronics *went beyond 100 pages only in anniversary issues. It wasn't until 1941, eleven years after the magazine was founded, that it hit 104.* —J. D. L.

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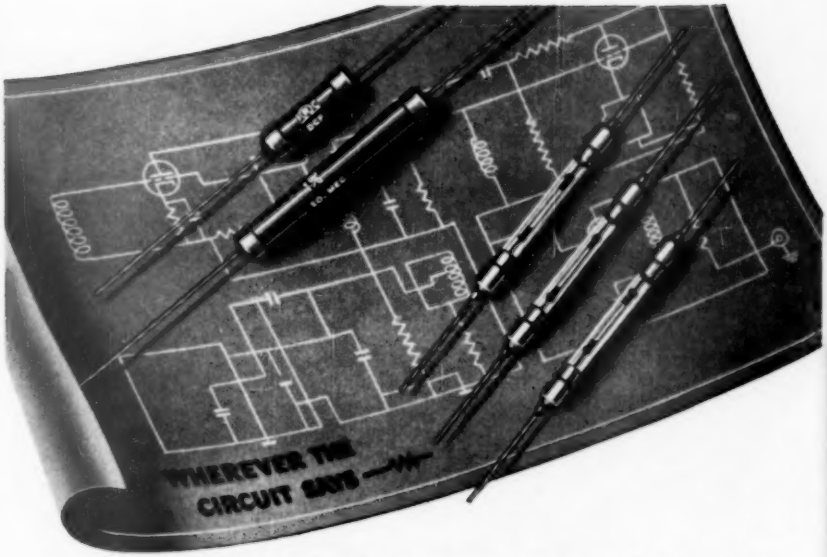

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New IRC Type UHR (Ultra High Resistance) Resistors actually provide resistance values of 10^8 to 10^{12} ohms inclusive! High resistance and small size make them suitable for use in such critical applications as atomic research instrumentation. Hermetically sealed in inert gas in glass tubes, the new UHR's are protected from mechanical damage and exposure to atmospheric conditions. Tolerances:— ±10% standard, ±5% and labeled to within ±1% of actual value at additional cost.

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Send for free Technical Data Bulletins on these IRC Resistors—and be sure to ask about our Industrial Service Plan. It enables your IRC Distributor to give you prompt delivery of maintenance and experimental quantities—right from his local stocks. International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa. In Canada: International Resistance Co., Ltd., Toronto, Licensee.

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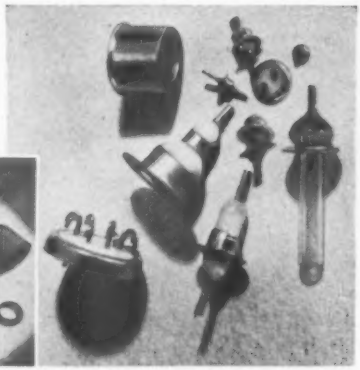

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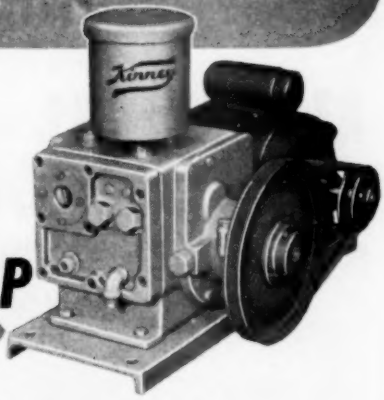

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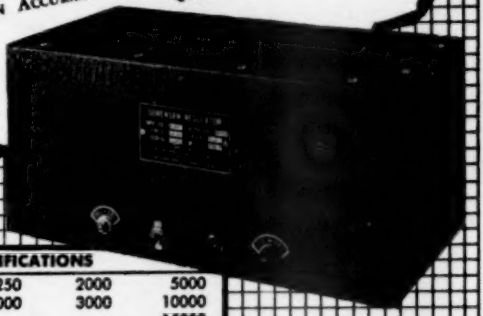

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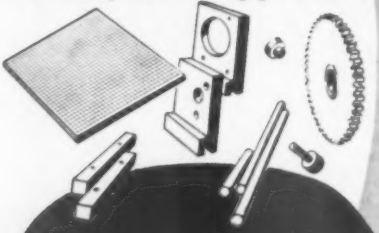

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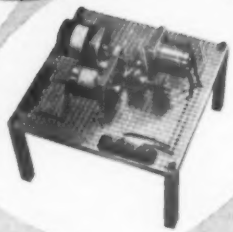

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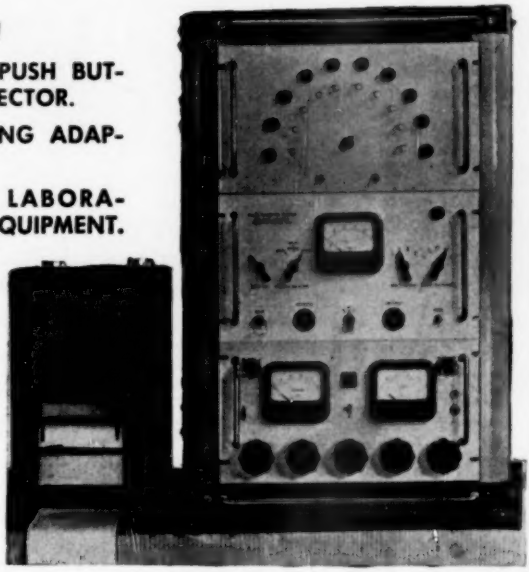

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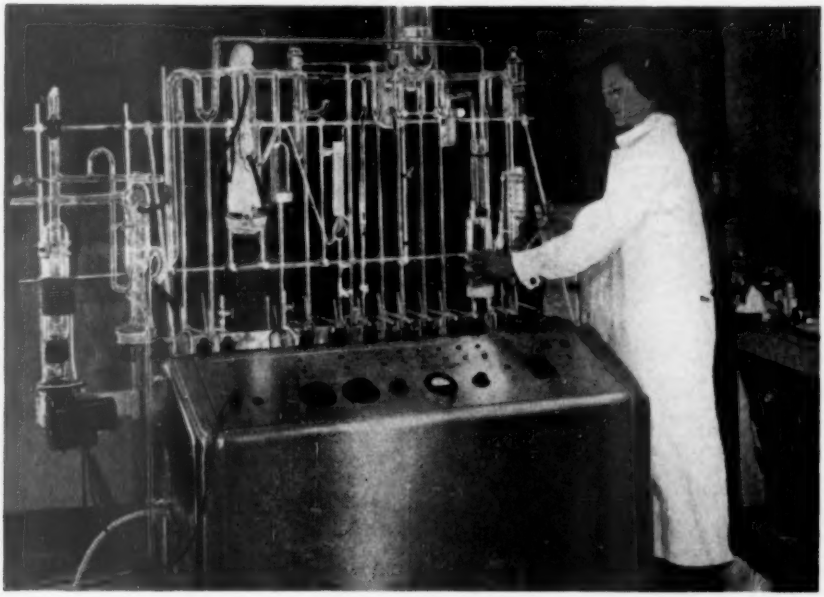

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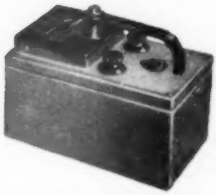

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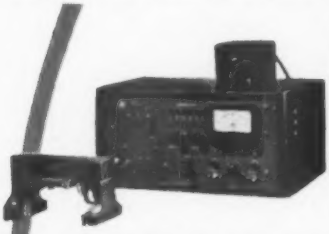

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